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GREENHOUSE EFFECT AND GLOBAL CLIMATE CHANGE

HEARINGS

BEFORE THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES UNITED STATES SENATE

ONE HUNDREDTH CONGRESS

FIRST SESSION

ON THE

GREENHOUSE EFFECT AND GLOBAL CLIMATE CHANGE

NOVEMBER 9 AND 10, 1987

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GREENHOUSE EFFECT AND GLOBAL CLIMATE CHANGE

MONDAY, NOVEMBER 9, 1987

U.S. Senate,
Committee on Energy and Natural Resources,
Washington, DC.

The committee met, pursuant to notice, at 9:35 a.m., in room SD-366, Dirksen Senate Office Building, Hon. Timothy E. Wirth, presiding.

OPENING STATEMENT OF HON. TIMOTHY E. WIRTH, U.S. SENATOR FROM COLORADO

Senator Wirth. The committee will come to order. Gentlemen, thank you very much for being with us this morning. I bring you greetings from Senator Johnston who is, as you know, one of the three Senate negotiators in the budget process. He is hoping to be able to drop by this morning but those negotiations are picking up in earnest. So, he sends you his thanks for appearing here and looks forward to seeing your statements.

When we originally scheduled this hearing, we thought that the Senate was going to be in session on Mondays in November. It now turns out that we are not, so we may have sparse attendance today. However, the purpose of this hearing, of course, is to develop a record.

As John Firor has told me, the science of the greenhouse effect is evolving rapidly. It has received broad consensus on the scientific community, and scientists are telling us that this is a very serious issue.

We are certainly hoping that we are going to be able to change that last phenomenon with the beginnings of your testimony today.

A number of members of the committee will have statements that they want to have included in the record, and those will be included in full in the record.

[The prepared statements of Senator Johnston and Senator Wirth follow:]

STATEMENT BY THE HONORABLE J. BENNETT JOHNSTON

Good morning ladies and gentlemen.

I am pleased to welcome you to this morning's hearings before the Committee on Energy & Natural Resources. The purpose of today's hearings is to take testimony regarding the build-up of carbon dioxide and trace gases in our atmosphere, commonly referred to as the Greenhouse Effect. We are fortunate to have with us a distinguished panel of witnesses made up of scientists and policy makers and I would like to extend my appreciation to all of you who have traveled to be here.

The purpose of today's hearing is to receive testimony regarding the growing scientific concern that by the next century, the temperature of the earth's atmosphere may increase to a level unmatched in thousands of years. Furthermore, this temperature change is projected to occur over mere decades, which will result in a climatic change five to ten times as great as that caused by the last ice age. This global warming may lead to rising sea levels, changing rainfall patterns, and greater extremes in weather. These changes could have enormous implications for our nation's agricultural systems, water supplies, forests, electric industry, and coastal cities.

Scientists believe that a global warming is occurring primarily as the result of human activities: the burning of fossil fuels, the destruction of the world's forests, and the introduction into the atmosphere of certain man-made trace gases. Of particular interest to this committee is the extent to which the burning of fossil fuels to meet this country's energy needs will cause potentially serious elevations in the emission levels of carbon dioxide and other trace gases. Some analysts argue that the relationship between the consumption of fossil fuels and global warming should be a major factor shaping our national energy policy. These hearings may show that in the process of forming a viable national energy policy it will not be enough to merely consider our dependency on foreign fossil fuel resources or their availability, but that it appears we must take into account global climatic changes as well. The members of this Committee must be in a position to fully understand the scientific theory underlying the Greenhouse Effect and its policy implications. I hope these hearings, the first in a series of Energy and Natural Resource Committee hearings dealing with global warming, will provide us not only with a greater perspective and understanding of this emerging problem, but also an overview of the policy options that may lie ahead.

Before I begin these hearings, I would like to mention that copies of all of today's testimony will be placed in the hearing record. Furthermore, the hearing record will remain open for two weeks in order to receive additional comments and materials.

Statement of the Honorable Timothy E. Wirth

November 9, 1987

Concerning the Greenhouse Effect and Global Climate Change

Mr. Chairman, I want to thank you for scheduling these hearings on the greenhouse effect and global climate change. While this Committee deals with very important and very difficult issues every day, none is more important to the future of the world's environment than the dramatic changes in global climate that are already being predicted.

We are scheduled to hear today from two panels of some of the most well respected and esteemed atmospheric scientists in the nation. I have known the first witness -- Dr. John Firor from the National Center for Atmospheric Research in Boulder, Colorado -- for many years. I know him to be a careful, thorough, and cautious scientist. Those are traits that describe every good scientist.

Today, these scientists are going to tell us that our use of energy and the destruction of the world's rain forests already have committed the Earth to a significant warming. More important, they are here to warn us that unless the United States government works with other governments around the world to redirect our energy policies and to halt deforestation, global climate change on a scale never before experienced by man could overwhelm our planet -- potentially in our lifetimes, certainly within the lifetimes of our children and grandchildren.

Today's witnesses come armed with predictions that leave little doubt that any part of the Earth would escape the effects of global climate change. In the Rocky Mountain West, the combined effects of global warming and reduced precipitation could diminish water supplies in the upper Colorado River basin by nearly forty (40) per cent. Those same changes in global climate would hasten the day when sugarbeet farmers in eastern Colorado and wheat farmers on the plains of Texas can no longer rely on the Ogallala aquifer for irrigation.

Across the middle of our continent and the mid-continent region of Europe, soil moisture could decline rapidly, leading to dramatic reductions in agricultural production. These regions are the breadbaskets of not just the United States and the Soviet Union, but much of the world.

But the Earth's coast lines may experience the greatest environmental change. As average temperatures rise, the world's glaciers and ice fields will recede and the ocean will warm and expand. Sea level could rise by a few feet, or by five feet or more. That would cause estnesive beach erosion in the East, salt water intrusion into the marsh lands of Louisiana, and would make the entire Gulf region much more vulnerable to hurricane damage. If the worst predictions come true, many of the world's great coastal cities could be inundated within a century.

Here in Washington, D.C., the temperature could exceed 100°F as many as twelve (12) times a year, not just an average of once a year. In Omaha, which lies at the center of our agricultural heartland, temperatures would exceed 100°F for as much as three weeks every year, rather than the average three days that we see today.

These are profound global climate changes by any objective measure. The scientists who are testifying today have alerted all of us to the environmental and social costs of global climate change. The challenge that lies before us now is to determine what must be done to head off as much of the climate change as we still can, and to begin planning for those global climate changes that are inevitable.

Once again, Mr. Chairman, I want to thank you for scheduling these hearings. This Committee will have to be deeply involved in this debate, since any legislative response to global climate change will require us to take a long, hard look at this nation's energy policy. These two days of hearings are an excellent first step, and I look forward to working with you in the months and years to come as we search for ways to address the problem of global climate change.

Senator **Wirth**. Our procedure this morning will be to ask each of you to summarize your testimony in the way that you think is most appropriate, and your statements will be included in full in the record. We will start with each of your statements. I will then ask you to comment on the testimony given by other members of the panel, and we will then get into questions.

I think the best way to start is just to move from left to right. What I would like you to do is to go down the panel and identify yourselves and your organization for the purposes of the record. Perhaps we can start with Dr. Firor from the National Center for Atmospheric Research.

John, perhaps you could identify yourself and then we will go right down the row and then start with Dr. Firor.

Dr. **Firor**. My name is John Firor and I am, as Senator Wirth said, from the National Center of Atmospheric Research in Bolder, Colorado.

Senator **Wirth**. If all of you also will tend very closely to the microphone. You have to speak right into the microphones here. They are not high technology microphones; they are U.S. Senate microphones, so you will have to speak right into them.

Dr. **Ramanathan**. I am V. Ramanathan, from the Department of Geophysical Sciences of the University of Chicago.

Dr. **Blake**. I am Donald Blake from the Department of Chemistry, University of California, Irvine.

Dr. **Hansen**. I am James Hansen from the Goddard Institute for Space Studies, New York City.

Dr. **Manabe**. I am Syukuro Manabe, from the Geophysical Fluid Dynamics Laboratory of National Oceanic and Atmospheric Administration located in Princeton, New Jersey.

Dr. **Leatherman**. I am Steve Leatherman from the University of Maryland, College Park.

Senator **Wirth**. Gentlemen, thank you very much for being here. Dr. Firor.

STATEMENT OF DR. JOHN FIROR, DIRECTOR, ADVANCED STUDY PROGRAM, NATIONAL CENTER FOR ATMOSPHERIC RESEARCH, BOULDER, CO

Dr. **Firor**. Thank you, Mr. Chairman. My task here today is to provide an overview of the problem that we are here to discuss, the so-called greenhouse effect.

This problem is quite easily described. There exists in the earth's atmosphere, certain gases that absorb infrared radiation. They trap heat that would otherwise escape from the earth and thereby warm the earth. This is a well known effect. And has been going on for a long time.

The earth completely depends on it for its biosphere. The earth would be frozen over completely if it were not for the greenhouse effect.

The problem that we want to discuss though is that these gases that provide the greenhouse effect began increasing in their concentration about 100 or 150 years ago thereby providing, perhaps, too much of a good thing by increasing the warming and providing the potential for rather dramatic climate changes.

I will mention two gases. There are many, but two of the important ones are useful to illustrate the problem. The first is carbon dioxide, whose origin is by in large, the burning of fossil fuel, and methane, whose origin is more diverse and less well understood. But, it can be associated with our agricultural activities since much of it comes from rice paddies, cattle, termites and so forth.

The amount of warming that seems likely to occur can only be judged as to whether it is important or not in terms of studies of past climate change. Let me talk for a moment about what happened when the last ice age retreated. For several thousand years the earth slowly warmed. It was a very slow warming compared to what we are discussing here today. Yet, that slow warming proceeding over several thousand years, completely redid the face of America.

Tree species that existed in Ohio and Michigan at the beginning of that period found it necessary to migrate far up into Canada in order to find a climate that they were comfortable with. Ohio and Michigan received tree species from the far southeastern part of the United States.

We have had smaller climate changes since that time, the so-called little ice age a centuries ago and a warm period in the Eleventh Century. These, too, can be shown to have had some measurable effects, particularly on societies that were already marginal.

The kind of climate change that is being projected now as a result of the increase of greenhouse gases is many times faster, five or 10 times faster, than climate changes that we have studied in the past. So, it is not something that we can measure against the past easily. It is something that is far beyond those past changes and hence, likely to be much more dramatic.

Will the forests have to migrate further? My friends who are experts in forestry say the problem is that this migration would have to be too fast. That a tree, by the time it matures and gets ready to drop a seed, would find that the climate had changed so much the seed could not take hold.

Therefore, it is possible with this rate of climate change that young trees would disappear largely from America, except for those small species that had very light seeds. We might end up with a country covered with scrappy shrubs of various kinds that could move more rapidly. I call that a "sumac world" that we may be aiming towards.

The sea level has increased already by a few inches. The sea level is likely to increase further in the future. As you know, an increase of even a foot or so would produce some dramatic changes in some parts of our country. In the third world there are large areas of low-lying lands which could be put at greater hazard due to storms if the sea level was higher.

There are many other impacts, and some of today's panelists will discuss them. But anytime you do calculations and foresee impacts of the kind that I have sketched out, people ask and should ask is this true; are you right? Just how reliable are these projections? We, of course, cannot do the experiment ahead of time and test the calculations, but we can try in every other way to build confidence in our ability to make these calculations.

We test the models in a number of ways, and I am sure that you have before you some of the world's leading experts on modeling and they will comment on their models and what they do to build up their confidence. But, I think it is fair to summarize the current feeling in the scientific community, that there is a strong consensus that if we continue to emit greenhouse gases into the atmosphere, that the climate will warm levels that may take us well outside any historical experience that we have had.

Let me summarize that by saying that anytime you predict something dramatic people will challenge you, they will mistrust you, and you yourself may wish that the results were not true. Keep in mind, that these calculations have been subjected to fairly rigorous treatment.

There are, of course, remaining uncertainties. There is debate over exactly how large this climate change will be at any one time. I have quoted that the rate of increase in temperature globally averaged will be five to 10 times that which we saw during the little ice age of the climatic optimum. Some people would say it is going to be as small as three times, still a very rapid increase. Some would say that it is greater than 10. There is quite a range of debate about the rate at which the climate will warm.

There is also considerable debate about how the local manifestations of this climate change will show up. Will any particular location sample this climate change? Will it warm faster or slower? If we have the average, of course, some places will be faster and some will be slower. In particular, will there be more or less rainfall? These are issues that remain to be cleared up, although some progress is being made and I am sure that you will hear about that today.

There is always the remaining uncertainty that there may be some effect that we have overlooked; there may be some problem that will change the results in a fairly major way. That is the reason that all of our colleagues subject these calculations and models to continuing testing against reality, testing against today's climate and yesterday's climate, historical reconstructions, testing against seasonal climates in every way possible to build up confidence and make sure that we have not overlooked some major future of climate change.

I have described how we may be putting our unmanaged forests at risk with the greenhouse warming, but it is legitimate for you to ask whether people who are a notoriously adaptable species, will not be able to find ways of adapting to almost any change that might come along.

I was recently a participant at a meeting with people from all over the world who were assembled to discuss just that question. This meeting was put together by UN agencies and a number of private foundations to ask the question, how do we adapt region by region to this climate change and what will it cost?

We divided up into working groups—an Arctic group, a mid-latitude group, wet tropics and dry tropics and so forth—sent the groups away with these questions: How in your region, will we adapt and what will it cost? The groups came back by in large with the answer: We cannot adapt. It is happening too fast, and therefore, we have to look at another possibility.

The tropical forest people did not have that answer. They did not quite know whether this change would effect tropical forestry strongly or not. Besides, they were worried about whether there would be any tropical forests left by the time the climate change got there.

In any case, the results of this meeting, after listening to each of these working groups, were that we must take prompt steps to slow this warming if we are to have a reasonable chance of adapting to it. That raises the question, can we slow the change? Carbon dioxide is a greenhouse gas which is driving this climate change most strongly, and it is put into the atmosphere largely by the burning of fossil fuels.

Two decades ago, I think that all of us believed that fossil fuels were tied in such an intimate way to the health and progress of our industrial society there was no way to touch them. They had to increase in a certain way. The major price increases in the 1970's caused reexamination of this assumption, and today you find a completely different attitude towards the connection of fossil fuel with the prosperity of our society.

There have been a number of reports written in the last 20 years by economists, environmentalists, business types, academy of science participants and mixed committees. Each and every report has come back saying, we ought to get started on energy conservation. If you read these reports in sequence, as I did in preparation for coming here today, you will find an interesting evolution.

The earlier reports written in say 1975, said we need to conserve energy because we had no choice. The more recent reports say we should conserve energy because it is an economically viable thing to do, we will make money in the process, and we will be able to do what we want to by living more efficiently.

So if the recent reports hold out a promise that we could set a goal of decreasing fossil fuel use in this country by numbers as large as 50 percent, cutting in half over the next 30 years, the total fossil fuel use used in this country, we could not only profit from reducing the pressure for climate change, but actually profit by working more efficiently at improving our competitive position, reducing urban pollution and in many other ways helping the country.

In the short time it is clear that these policies, those that will reduce our use of fossil fuel, are the quickest and best ways of getting at the problem of slowing this climate change. The longer term is more difficult. For the longer term, we must examine the difficult problems of how to develop major sources of renewable energy; we must look into how do we stabilize the population of the earth and our country; and, we must look at what kind of sensible aid that we can give to the Third World to help them move to the prosperous future they desire without repeating the fossil fuel evolution that we went through.

There are a number of policies which I hope the committee will consider as it considers the information that it will receive in these two days; ways of moving our use of coal into natural gas. All fossil fuel is not equal when it comes to carbon dioxide, and natural gas produces only half as much carbon in the atmosphere as coal when we use it.

We need to encourage efficient fossil fuel use in all aspects; we need to reduce total fossil fuel use; we need to encourage the development of alternative energies. I mentioned methane as a gas. I have not come back to that, because we know less. We need to study methane more intensively to find out how we can get a handle on it.

We need, of course, to engage in the long tedious effort of international negotiations to make sure that the other parts of the world are going along with us.

You have here in this room, experts who have spent years or entire scientific careers working on this problem. You also have people who are interested in the economic and social aspects of energy. I suspect, if you had the patience, we could talk to you for weeks upon end about the details of what we believe and think and study, and the strengths and weaknesses of our argument and all the details.

Amid this bountiful complexity, a few simple themes stand out, and I want to end with these themes. The first one is, there are now so many of us here on earth and each of us on the average uses so much energy that we can change the physical world.

Second, we are already changing the chemistry of the atmosphere, and through that chemistry the heat balance of the entire globe. Third, the best judgments of the most experienced scholars, is that these changes will soon be large and important.

Fourth, there are steps that we can take promptly that will slow a fraction of these changes and give us a reasonable chance of learning to cope with the rest.

Thank you.

[The prepared statement of Dr. Firor follows:]

TESTIMONY TO BE GIVEN BY DR. JOHN FIROR, NATIONAL CENTER FOR ATMOSPHERIC RESEARCH, BEFORE THE SENATE COMMITTEE ON ENERGY AND NATURAL RESOURCES, NOVEMBER 10, 1987.

Mr. Chairman, Members of the Committee:

My task before you today is to provide an overview of a growing problem concerning the earth's climate, a problem which also deeply involves energy and natural resources. This problem is easily described: Certain gases that can absorb infrared radiation are appearing in increasing concentrations in our atmosphere. At today's concentrations these gases are trapping heat that would otherwise escape from the atmosphere and are thereby warming the surface of the earth. And, because the concentrations of these gases are increasing, we can expect this climate warming to accelerate in years to come. We use the name "Greenhouse Effect" for this phenomenon.

Human activities are the major cause of the increases in the amounts of the greenhouse gases in the air. The most important such gas is carbon dioxide, and the increase in that gas in the atmosphere is the result of the burning on fossil fuel and, to a lesser extent, of the destruction of forests. Another important greenhouse gas is methane. Its sources are more varied than those of carbon dioxide and include swamps, municipal waste dumps, and coal mines and leaking natural gas pipelines. But the largest sources are thought to be rice paddies, the intestines of cattle and termites, and anywhere else that organic material decays without being in contact with air. It is a useful simplification to say that carbon dioxide increases comes from our industrial, transportation, and domestic activities, and that methane comes from our agricultural activities. There are other greenhouse gases, but let me focus on these two.

Studies of past climate changes can tell us something about what to expect. We find that even a slow change in climate can have dramatic effects if it continues long enough. As the last ice age retreated the earth warmed, slowly, for several thousand years. This change completely rearranged the face of America. Trees species that grew in Ohio and Michigan had to migrate far up into Canada to find a climate they could thrive in, and other kinds of trees from the deep South moved into Ohio and Michigan. There have been smaller climate changes since - the so-called Little Ice Age a few centuries ago and a warm period in the Eleventh Century, both of which damaged marginal societies.

Let us then compare the greenhouse climate change we project with these historical events. If the greenhouse problem continues unabated, its effects by late in the next century will rival those of the ice age retreat. But sooner and more important: the greenhouse change is projected to be five to ten times as fast as any climate change we know about since that time.

Will the forests have to migrate further? Experts in forest studies tell me that the the effect will be quite different this time. They believe that many trees cannot migrate five or ten times as fast as they did back then - by time a tree matures enough to produce seeds the climate will be unfavorable for those seeds to take hold and produce the next generation. We thus could be heading towards a country almost devoid of young trees, a country given over to shrubs that can tolerate a wide range of conditions - a "sumac world".

The level of the sea increased during the retreat of the ice age, and we can expect further sea level rise. Even a one foot rise would give problems to certain areas of our country, and world-wide there are large, low-lying areas that, with any increase in sea level, will become more vulnerable to storm-blown waves.

There are many other impacts to be expected from such a rapid change in conditions. But with these sorts of possibilities in view we must stop and ask: just how reliable are these climate projections? Scientists attempting to answer this question use as their tool numerical simulations, or numerical models, of the climate. They put together as much of their detailed understanding of the forces that drive the climate as they can fit into the world's largest computers, and they calculate what the climate will be like with more greenhouse gases in the air. In a few minutes you will hear from some of the world's premier developers of climate models, so I will not attempt to describe this process. The most difficult problem we all face is deciding how much trust one can place on the model calculations when they are used to foresee some aspect of the future. That is especially true if the models forsee, as they do, a dramatic and possible overwhelming climate change. Thus the models have received intense and repeated scrutiny and have been tested in a number of ways. These climate models, for example, have been used to calculate today's climate, and the results compared in great detail with what we actually observe. The models have been used to compute past climates where reconstructions are available, and again, comparisons made. They have been used to calculate the difference between summer and winter - a brief but quite large climate change. And related models have been used to compute the climates of Mars and Venus, one of which has much less of a greenhouse atmosphere than we do, and one much more. Also, several times a year, a scientific colleague will show up with a new speculation about some process that would modify the greenhouse change, and the modellers must than make special calculations with their models to check that suggestion or even to modify the structure of the models to try out the idea.

I could go on, but the point I wish to make is that there has been a vigorous and continuing attempt to convince ourselves that we need not worry about the greenhouse effect, and we have failed in this effort. The models have passed the increasingly difficult tests to which they are subjected, and our confidence in these models has grown. There is today a strong scientific consensus that the global warming projected by these models must be taken seriously.

There are two major remaining areas of uncertainty and controversy with the models. The first is in just how big the average effect will be. Different models give somewhat different estimates. The number I have used - that the change will be five to ten times as fast as when we came out of the last ice age - is somewhere near the middle. Some models say three times; some say more than ten. There is an additional uncertainty that will always be with us when dealing with anything as complex as the climate. We must constantly consider whether we have left out something important that would change the answer in a major way - hence the repeated testing process I described a minute ago.

The other area of uncertainty is in local effects - how much of the warming will show up at each location on earth and will each place get more or less rain. There is the consensus I described among scientists that we have got the average value about right, but there is still much work to do to get the details straight. All of the models show the world getting warmer, for example, but but only most of the models show the midwestern U.S. getting dryer. These uncertainties should be resolved as speedily as we can; better information can mean better planning.

I have described how we put our unmanaged forests at risk with the greenhouse warming, but it is legitimate to ask whether humans - a notoriously adaptable species - can arrange to adapt to the changes a climate warming will bring. Last month, I was part of a group from all around the world brought together by a UN agency and a number of private foundations to study just such a question. We were divided into working groups to look at different regions of the earth - arctic, mid-latitude, and so on - and try to answer the question "What steps must we take to adapt to the projected climate change and how much will it cost?" Each group (except the tropical forest people - they have even more pressing problems) came back with the same answer - we cannot adapt, they said, the change will be too fast. The mid latitude group explored the migration of forests that I spoke of earlier and concluded that no reasonable number of seedling farms and planting programs could maintain the natural forests. The sea level group, which included some experienced hydraulic engineers from the Netherlands and elsewhere, came back and said

"We can build dikes to hold back the sea in all the places where needed, but the world doesn't have enough money to pay for it." The arctic people said they would enjoy running ships in summer in the arctic sea, but that the thawing of the permafrost would unfortunately expose vast peat beds to decay - decay that would release great quantities of carbon dioxide to the air speeding up the whole process. The final conclusion of the meeting was that we must take prompt steps to slow the warming if we are to have a reasonable chance to adapt.

But can we slow this change? Carbon dioxide is the greenhouse gas most driving the climate change, and carbon dioxide is placed in the atmosphere in large quantities by the use of fossil fuel. If we are to slow the warming, we must use less fossil fuel. Two decades ago most of us thought that fossil fuel was so closely associated with our prosperity that indeed we could not, or at least should not, slow its use. But the price increases of the 1970 caused major reexamination of that assumption. There have been many studies on this question by all sorts of groups - scientific groups, engineering groups, economists, environmentalists, learned academies, and mixed committees of all sorts. Almost without exception, these studies call for energy conservation as the top priority step in dealing with our problem, either the problem of energy supply or the problem of climate change. In addition, if you read these reports in sequence as I have done, you see an interesting evolution. The early reports call for conservation because they feared we had to, whether it was desirable or not. The later groups are much more cheerful. The call for conservation through improvements in the efficiency with which we use energy, and they see such steps as not only solving problems but economically desirable as well. These later groups seemed to have surprised themselves when they looked at the details. They find the opportunities for efficiency improvements larger, not smaller than they had thought, and they note that in all the major areas of energy use, building heating and lighting, appliances, transportation, already proven techniques are available to do more with less. So, in the short term, policies to encourage efficient use of energy seem universally recognized as the quickest and easiest way to get started on what must be done. For the longer term we must examine the difficult problems of developing major sources of renewable energy, of stabilizing the population of our country and the earth, and of aiding Third World countries to move toward the prosperous future they desire without repeating the fossil fuel evolution of the now developed world.

The increase in methane in the air is more difficult to resolve. The sources are more diverse, and the atmospheric chemistry is less well understood. Here we must hope that more studies will show ways in which the emissions can be slowed.

I urge that as you develop information about this problem you also consider a wide range of possible responses aimed at stabilizing the composition of our atmosphere. Examples of such steps would be:

1. Encourage the replacement of coal with natural gas. All fossil fuels are not equal when it comes to carbon dioxide. For the same heat, natural gas produces half

as much carbon dioxide as coal.

2. Encourage efficiency in all fossil fuel use, by means of subsidy, taxes, or regulation, and help other countries do likewise.
3. Reduce total fossil fuel use.
4. Encourage the improvement of alternative energy sources.
5. Encourage the study of methane and other greenhouse gases.
6. Begin the long process of international negotiations on steps to stabilize the composition of the atmosphere.

Senator **Wirth**. Thank you very much, Dr. Firor.

Dr. Ramanathan.

STATEMENT OF DR. V. RAMANATHAN, DEPARTMENT OF GEOPHYSICAL SCIENCES, UNIVERSITY OF CHICAGO, CHICAGO, IL

Dr. **Ramanathan**. Mr. Chairman, I appreciate the privilege of testifying to this committee on this global problem.

I will first start with some of the simple facts regarding what we know about the increase. We know from measurements that several trace gases in the atmosphere have been increasing since the dawn of the industrial era. In fact, let us see what has happened in the last decade.

[Viewgraph.]

What we see here is a synthesis of all the available measurements taken of the globe, right from the northern Pacific Ocean to the Atlantic, of how the various gases starting from carbon dioxide, methane, nitrous oxide. The group on the left side are all related to energy sources. The right side are chlorofluorocarbons that are used as refrigerants and propellants, methyl chloroform, which is used in a decreasing agent; and carbon tetrachloride. These are just a few examples of some of the numerous gases which are increasing in the atmosphere.

Why, as scientists are we concerned about this increase? As Dr. Firor mentioned, they start a global warming process that has the so-called greenhouse effect. I will take a few moments to explain what the greenhouse effect means.

The gases shown in figure 1 trap the infrared radiation, which is also known as heat radiation, emitted by the surface of the earth which would have otherwise escaped in to space. It is this trapping of the infrared which is referred to as the greenhouse effect, particularly since these gases let the visible light from the sun penetrate to the ground. Incidentally, this infrared is what you see when you take an infrared camera and look at the roof of your house.

Next, let me go from the greenhouse effect, which is well understood as Dr. Firor mentioned, to the global climate change. An increase in the concentration of these gases leads to increased trapping of this infrared, and thus causes an excess of radiative energy available to drive the climate system.

What is the effect of this excess energy? Again, I would emphasize, based on very sound physical principles, we believe this excess heating will drive a vigorous climate system. I will give you one example of what I mean by a vigorous climate system.

This excess heating would warm the global oceans, which in turn from well known thermal dynamics, will evaporate more moisture into the atmosphere. What goes up ultimately has to come down, which means there is an increase in global rainfall. Hence, a greenhouse rich atmosphere will be warmer, more humid, and also wetter.

I also want to emphasize another important point which will come out in the presentations of Dr. Hansen and Manabe. It is this radiative heating and the humidity in the atmosphere which drives the global wind patterns on the various regional climates. By altering the radiative heating, from sound physical principles, you would expects shifts in the regional climate pattern as well as wind distribution.

Next, let me go on to what are the predicted climate changes. One thing which we reasonably know how to do, is to compute the magnitude of the increase in the greenhouse force. An example of this is shown in the next figure, which we have tracked down with the calculations from Dr. Hansen's group at NASA/Goddard. Based on what we infer to be the observed changes of the gases, the greenhouse heating of the planet has changed from the decade of 1850 on up to 1985 on the top panel. The details of that is not too important at this stage.

I wanted to emphasize two issues there. First, if you go from the left side of the panel to the right side on the top, you find out that the rate of the decadal increase in the energy trapped in the planet is now about five times greater than the the mean rate for the early period of 1850 to 1960.

The second issue, which is going to be very important in terms of policy-making, is the Non-CO_2 trace gases, the gases other than CO_2 in the atmosphere, are now adding to the heating by an amount comparable to the effect of CO_2. So, it would be a mistake to view this as a CO_2 problem alone. You have to really look at the whole issue.

Next, let me talk about the magnitude of the predicted climate change. As far as the global warming is concerned, the cumulative increase in the greenhouse force until 1985 has committed the planet to an equilibrium warming of about 1 to 2.5 degrees centigrade. What do I mean by equilibrium warming? It is the basically, the warming that is already in the lag. Again, let me give you an example of what I mean by being in the lag. If, for example, by draconian measures we decide that we have had enough, we are not going to allow any further increases, that is, we hold the level of 1985 that warming of 2.5 degrees which still can be seen in the climate system. The climate system will ultimately warm to that.

Next, if we continue for example, business as usual and ignore the theory completely, then the theory suggests that at the current observed rate of increasing trace gases, the greenhouse warming would increase by about 0.2 to 0.5 degree celsius per decade.

Hence, if emission of pollutants produced by human activities continues unabated, the predicted warming can exceed several degrees celsius by the middle of the next century.

The fourth point in terms of the predicted change, as I mentioned earlier, is the earth as a whole would be more humid and wetter. I think Dr. Hansen or Dr. Manabe would point out to you that the warming will be amplified significantly in the polar regions due to melting of sea-ice and snow cover.

The next issue that I want to come to is the timing of the warming. The most important effect of the increase in the trapping of this infrared heating, is to simply push the climate system out of equilibrium with the incoming solar energy. You can sort of imagine the system is in harmony on a time scale of several centuries, of what is coming in and what is going out.

In this harmonious system, the world's oceans, the distribution of sea-ice, the clouds, the biosphere and the land as Doctor Firor pointed out, are all driven out of equilibrium with respect to the energy fluxes maintaining their present state.

The climate system, of course, cannot restore the equilibrium instantaneously. Hence the warming in terms of when the predicted magnitude of the change would manifest the lag behind the trace gas increases.

Current models indicate that this lag will range between several decades to a century. So in a sense, the timing of the warming is one of the most uncertain aspects of the theory. It is sort of unfortunate, because that is one of the things which one wants from the modern theory to double up a ration of policy-making. That is when the theory is not prepared to pin down when this magnitude will manifest itself.

I want to also talk about a comment on the climate extremes, and I found this also in Dr. Hansen's testimony. Surface warming as large as that predicted by the models for the next century would be unprecedented because the present climate is just coming out of what we call the peak of an interglacial.

The earth's climate sort of oscillates between glacial ice age and interglacial periods with a temperature variation of about 5 degrees centigrade. The last great icing, for example, peaked between 14,000 to 22,000 years ago, and warmed to a warm interglacial with a peak occurring around 5,000 years ago. Hence, a human induced global warming of about 5 degrees during this interglacial period would be beyond the range of extreme climates that have occurred during, at least, the last million years.

I also point at some of the major uncertainties in the theory which involves or are still not grappling with the various feedbacks in the system.

I want to end my testimony by stressing an issue which is often ignored, and it is gradually being perceived that this greenhouse effect is interrelated with the ozone problem, which is also coming to head because of the change in the Antarctic ozone. Let me give you one example.

The chlorofluorocarbons, the CFC 11 and 12 which I pointed out as important greenhouse gases, are also the same gases which according to theory, lead to destruction of the stratospheric ozone. So, there is a connection between the two.

The second is, any ozone change in the stratosphere would influence climate because ozone traps the ultraviolet radiation from the sun. When you decrease the ozone you allow more solar heating to reach the ground which would tend to create a warming.

The second thing that I want to point out again is, the tropospheric ozone, ozone in the first 10 kilometers of the atmosphere, is an important greenhouse gas. Several pollutants like carbon monoxide, nitrous oxide, which are all related to energy consumption as well as methane and other oxides of nitrogen through chemical reactions can lead to an increase in the lower atmosphere ozone which can, again, cause an additional warming.

I am just giving you a few examples of some of the emerging issues that increasingly suggest a very strong coupling between the greenhouse and the ozone problem.

Thank you.

[The prepared statement of Dr. Ramanathan follows:]

Observed Increases in Greenhouse Gases and Predicted Climatic Changes

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Testimony to United States Senate, Committee on Energy and Natural Resources
Washington,DC 20510, Monday, November 9, 1987

About three years ago, an international panel on the trace gas climate problem was commissioned by the following agencies:

World Meteorological Organization
National Aeronautics and Space Administration
Federal Aviation Administration
National Oceanic and Atmospheric Administration
The United Nations Environmental Program
Commission of European Communities

This panel deliberated for a period of about 18 months and the findings of this panel appeared in a scientific journal in 1987 as follows:

Title: Climate-chemical interactions and effects of changing atmospheric trace gases
Journal: *Reviews of Geophysics* Volume 25, pp. 1441-1482, August 1987.
Authors: V. Ramanathan, L. Callis, R. Cess, J. Hansen, I. Isaksen, W. Kuhn, A. Lacis, F. Luther, J. Mahlman, R. Reck, and M. Schlesinger

My testimony is largely based on the above paper.

Observed Increase in the Pollutants.

Since the dawn of the industrial era, several trace gases have been increasing in the atmosphere. Recent advances in chemical measurements have helped document the rate of increase of the trace gas concentrations. The concentrations continue to increase at significant rates as shown in Fig. 1 for carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), carbon tetrachloride (CCl_4), chloro-fluorocarbons (CFC), CFC11 and CFC12, and methyl chloroform (CH_3CCl_3). The industrial sources for these gases as well as several others that have been detected in the atmosphere are given in Table 1. Studies of the chemical balance of the land-ocean-atmosphere system provide compelling arguments for attributing the observed increases to human activities such as: fossil fuel consumption; deforestation; refrigerants; propellants; and numerous others.

Scientific concern for the climatic effects of an increase in the atmosphere concentration of CO_2 dates back to the nineteenth century. It is only within the last decade that we have become aware that human activities are causing an increase in the atmospheric concentrations of not only CO_2 but several other trace gases as well.

The Greenhouse Effect:

The gases shown in Fig. 1 trap the infrared (IR) radiation, also known as heat radiation, emitted by the surface of the earth which would have otherwise escaped to space. It is this trapping of the IR radiation which is referred to as the greenhouse effect, particularly since the gases let the solar radiation (visible light) penetrate to the surface. The synthetic trace gases are significantly more effective than others in enhancing the greenhouse effect. For example, adding one molecule of CFC11 and CFC12 to the atmosphere can have the same radiative effect as adding 10,000 molecules of CO_2.

A Vigorous Climate:

An increase in the concentration of the greenhouse gases leads to increased trapping of IR radiation and thus causes an excess of radiative energy available to drive the climate system. This excess energy will alter global and regional climate patterns since radiative energy (solar and IR) is the fundamental energy source for climte and the winds in the atmospere and the oceans. The result, according to the theory, is a vigorous climate system. For eample, the excess radiative energy will warm the oceans. The warmer oceans will evaporate more moisture. The excess moisture in the atmosphere will increase global rainfall. Hence, a greenhouse rich atmosphere will be warmer, more humid and wetter. However, because of non-linear interactions between radiative heating and atmospheric circulation, the warming and rainfall changes will not be uniform, but will vary significantly with latitude, region and season. In essence, shifts in the climate patterns should be anticipated.

Predicted Climate Changes:

- The decadal increase in the greenhouse forcing from the decade of 1850 to 1980 as well as from the projected increases are shown in Fig. 2. The rate of decadal increase of the total radiative heating of the planet is now about 5 times greater than the mean rate for the early part of this century. Non-CO_2 trace gases in the atmosphere are now adding to the greenhouse effect by an amount comparable to the effect of CO_2 increase.
- The cumulative increase in the greenhouse forcing until 1985 has committed the planet to an equilibrium warming of about 1 to 2.5 °C. The 2.5 °C is based on the sensitivity of three dimensional climate models.
- At the current observed rate of increase in the trace gases, the greenhouse warming of the globe increases by 0.2 to 0.5 °C per decade. Hence, if emission of pollutants by human activities continue unabated, the predicted warming can exceed several degrees °C by the middle of the next century.
- The earth as a whole will be more humid and wetter
- The warming will be amplified significantly in the polar regions due to melting of sea-ice and snow-cover.
- Because of feedbacks involving the radiation, water cycle, clouds, atmospheric winds, sea-ice and oceans, shifts in climate patterns can be anticipated.

Out-of-Equilibrium Climate and Timing of the Warming

The most important effect of the increase in the trapping of the IR radiation energy by the trace gases is to drive the climate system out of equilibrium with the incoming solar energy. Consequently, the world oceans, the distribution of sea-ice, the clouds, the biosphere and the land are all driven out of equilibrium with respect to the energy fluxes maintaining their present state.

The climate system can not restore the equilibrium instantaneously, and hence the surface warming and other changes will lag behind the trace gas increase. Current models indicate that this lag will range between several decades to a century. However, analyses of temperature records of the last 100 years as well as proxy records of the paleo-climate changes indicate that climate changes can also occur abruptly instead of a gradual return to equilibirum as estimated by models. The timing of the warming is one of the most uncertain aspects of the theory.

Climate Extremes:

Surface warming as large as that predicted by the models for the next century would be unprecedented because the present climate is just coming out of the peak of an interglacial. The earth's climate oscillates between glacial (ice age) and interglacial periods with a temperature variation of about 5°C. The last great ice age peaked between 14000 to 22000 years ago and warmed to an interglacial with the peak occurring around 5000 years ago. Hence, a human induced global warming of 5°C during an interglacial period would be beyond the range of extreme climates that have occurred during ,at least, the last million years.

Major Uncertainties in the Predictions:

The timing of the warming is one of the major uncertainties. Next is the role of climate feedbacks that govern the magnitude of the warming. One of the least understood is how clouds will respond to the climate change and, how these changes, in turn, will influence the climate. The cloud feedback question arises because clouds are very powerful regulators of the radiative heating of the planet. The next potentially important feedback is the feedback between vegetation and climate. This feedback arises because the greenhouse effect significantly perturbs the cycling of water between the oceans, the atmosphere and the continents.

Connections with the Ozone Problem:

Roughly 85% of the ozone resides between 12 and 50 km, the region referred to as the stratosphere. The stratospheric ozone absorbs UV radiation from the sun, and hence regulates solar energy reaching the ground. Thus a decrease in stratospheric ozone allows more solar energy to penetrate to the ground, which would warm the surface. At the same time, ozone is a greenhouse gas, and hence a decrease in ozone would decrease the IR warming. The net climate effect of ozone changes in the stratosphere will depend on where in the atmosphere the ozone is destroyed. In addition, a decrease in stratospheric ozone would cause a severe cooling of the stratosphere and alter the stratopheric winds. The potentially strong destabilizing effect of a severe stratospheric cooling, occurring in conjuction with a lower atmosphere warming by the greenhouse gases, has not been factored into any current model studies.

Furthermore, tropospheric ozone is an important greenhouse gas. Changes in methane, carbon monoxide and nitrogen oxides, through chemical reactions, can lead to an increase in tropospheric ozone which can cause an additional warming. The above examples are some of the emerging issues that increasingly suggest a strong coupling between the greenhouse and the ozone problems.

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[illegible] Atmosphere of Years 1980 and 2030

Chemical Group	Chemical Formula	Dominant Source*	Dominant Sink*	Estimated Average Residence Time (τ_r), years	Year 1980 Global Average Mixing Ratio, ppb†	Year 2030 Probable Global Average Concentration, ppb‡		Remarks§
						Probable Value	Possible Range	
Carbon dioxide	CO_2	N, A	O	2	339×10^3	450×10^3		Based on a 2.4% per year increase in anthropogenic CO_2 release rates over the next 50 years.
Nitrogen compounds	N_2O	N, A	S(UV)	120	300	375	350–450	Combustion and fertilizer sources.
	NH_3	N, A	T	0.01	<1	<1		Concentration variable and poorly characterized.
	$(NO + NO_2)$	N, A	T(OH)	0.001	0.05	0.05	0.05–0.1	Concentration variable and poorly characterized.
Sulfur compounds	CSO	N, A	T(O, OH)?	1(?)	0.52	0.52		Sources and sinks largely unknown.
	CS_2	N, A	T	1(?)	<0.005	<0.005		Sources uncharacterized.
	SO_2	A(?)	T(OH)	0.001	0.1	0.1	0.1–0.2	Given the short lifetime, the global presence of SO_2 is unexplained.
	H_2S	N	T(OH)	0.001	<0.05	<0.5		
Fully fluorinated species	CF_4(F14)	A	I	>500	0.07	0.24	0.2–0.31	Aluminum industry a major source.
	C_2F_6(F116)	A	I	>500	0.004	0.02	0.01–0.04	Aluminum industry a major source.
	SF_6	A	I	>500	0.001	0.003	0.002–0.05	
Chlorofluorocarbons	$CClF_3$(F13)	A	S(UV), I	400	0.007	0.06	0.04–0.1	All chlorofluorocarbons are of exclusive man-made origin. A number of regulatory actions are pending. The nature of regulations and their effectiveness would greatly affect the growth of these chemicals over the next 50 years.
	CCl_2F_2(F12)	A	S(UV)	110	0.28	1.8	0.9–3.5	
	$CHClF_2$(F22)	A	T(OH)	20	0.06	0.9	0.4–1.9	
	CCl_3F(F11)	A	S(UV)	65	0.18	1.1	0.5–2.0	
	CF_3CF_2Cl(F115)	A	S(UV)	380	0.005	0.04	0.02–0.1	
	$CClF_2CClF_2$(F114)	A	S(UV)	180	0.015	0.14	0.06–0.3	
	CCl_2FCClF_2(F113)	A	S(UV)	90	0.025	0.17	0.08–0.3	
Chlorocarbons	CH_3Cl	N(O)	T(OH)	1.5	0.6	0.6	0.6–0.7	Dominant natural chlorine carrier of oceanic origin.
	CH_2Cl_2	A	T(OH)	0.6	0.03	0.2	0.1–0.3	A popular reactive but nontoxic solvent.
	$CHCl_3$	A	T(OH)	0.6	0.01	0.03	0.02–0.1	Used for manufacture of F22; many secondary sources also exist.
	CCl_4	A	S(UV)	25–50	0.13	0.3	0.2–0.4	Used in manufacture of fluorocarbons; many other applications as well.
	CH_2ClCH_2Cl	A	T(OH)	0.4	0.03	0.1	0.06–0.3	A major chemical intermediate (global production = 10 Tg/yr); possibly toxic.
	CH_3CCl_3	A	T(OH)	8.0	0.14	1.5	0.7–3.7	Nontoxic, largely uncontrolled degreasing solvent.
	C_2HCl_3	A	T(OH)	0.02	0.005	0.01	0.005–0.02	Possibly toxic, declining markets because of substitution to CH_3CCl_3.
	C_2Cl_4	A	T(OH)	0.5	0.3	0.07	0.03–0.2	Possibly toxic, moderate growth owing to substitution to CH_3CCl_3.
Brominated and iodated species	CH_3Br	N	T(OH)	1.7	0.01	0.01	0.01–0.02	Major natural bromine carrier.
	$CBrF_3$(F13B1)	A	S(UV)	110	0.001	0.005	0.003–0.01	Fire extinguisher.
	CH_2BrCH_2Br	A	T(OH)	0.4	0.002	0.002	0.001–0.01	Major gasoline additive for lead scavenging; also a fumigant.
	CH_3I	N	T(UV)	0.02	0.002	0.002		Exclusively of oceanic origin.
Hydrocarbons, CO, and H_2	CH_4	N	T(OH)	5–10	1650	2340	1850–3300	A trend showing increase over the last 2 years has been identified.
	C_2H_6	N	T(OH)	0.3	0.8	0.8	0.8–1.2	Predominantly of auto exhaust origin.
	C_2H_2	A	T(OH)	0.3	0.06	0.1	0.06–0.16	No trend has been identified to date.
	C_3H_8	N	T(OH)	0.03	0.05	0.05	0.05–0.1	No trend has been identified to date.
	CO	N, A	T(OH)	0.3	90	115	90–160	No trend has been identified to date.
	H_2	N, A	T(SL, OH)	2	560	760	560–1140	
Ozone	O_3 (Tropospheric)	N	T(UV, SL, O)	0.1–0.3	F(Z)∥	12.5%		A small trend appears to exist, but data are insufficient.
Aldehydes	HCHO	N	T(OH, UV)	0.001	0.2	0.2		Secondary products of hydrocarbon oxidation.
	CH_3CHO	N	T(OH, UV)	0.001	0.02	0.02		1980 concentration estimated from theory.

From *Ramanathan et al.* [1985].

*N: natural; A: anthropogenic; O: oceanic; S: stratosphere; UV: ultraviolet photolysis; T: troposphere; OH: hydroxyl radical removal; I: ionospheric and extreme UV and electron capture removal; and SL: soil sink.

†These concentrations are integrated averages; for chemicals with lifetimes of 10 years or less, significant latitudinal gradients can be expected in the troposphere; for chemicals with extremely short lifetimes (0.001–0.3 years), vertical gradients may also be encountered.

‡These values are not used in the present assessment.

§Also see text for details.

Varies from 24 ppbv at the surface to about 70 ppbv at 9 km. The concentration was increased uniformly by the same percentage from the surface to 9 km.

Observed Trace Gas Increases Over a Decade: 1975 to 1985

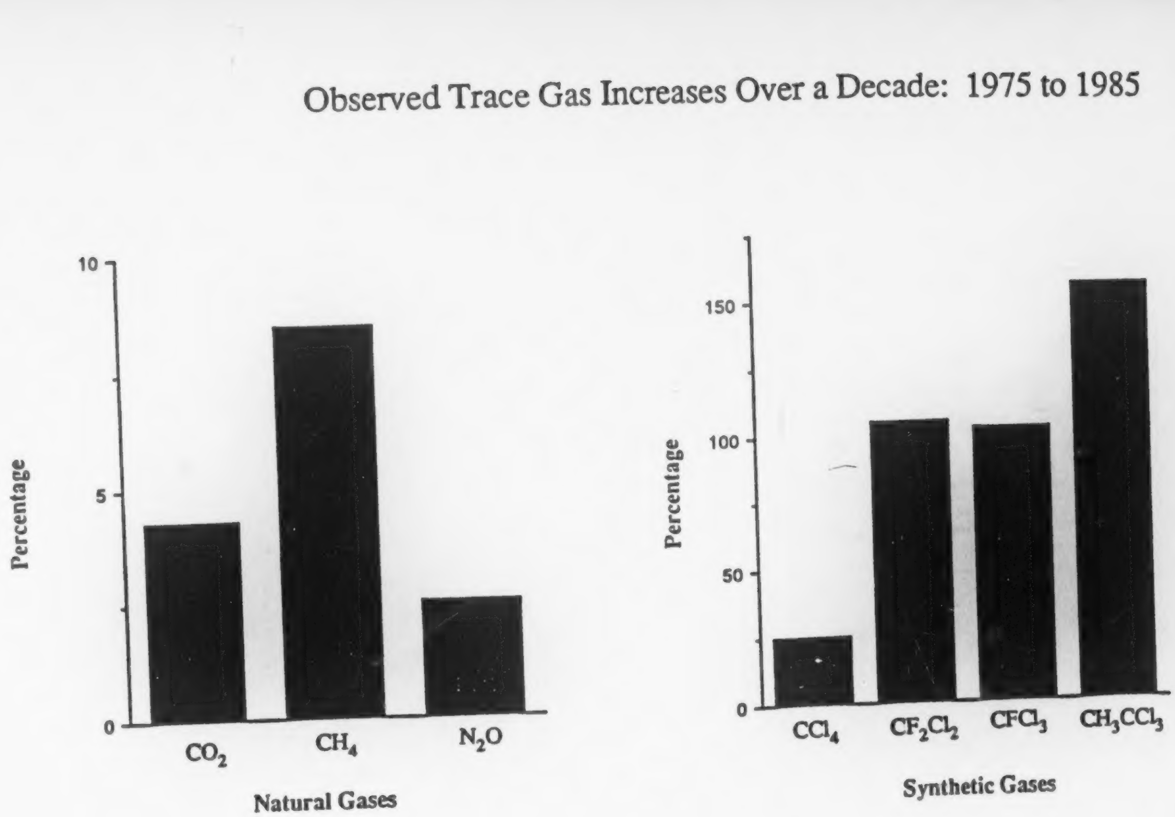


Fig. 1 Observed trace gas increases over a decade from 1975 to 1985. CO_2 data is taken from Bolin et al, 1987 and all others are taken from Rasmussen and Khalil, 1986.

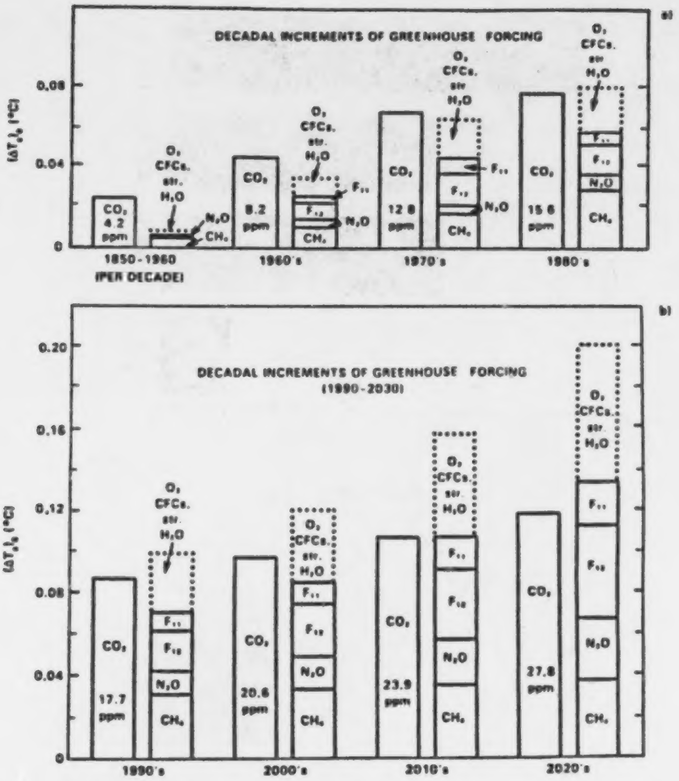


Fig. 2 Decadal additions to global mean greenhouse forcing of the climate system. The $(\Delta T_e)_0$ is the computed temperature change at equilibrium ($t \rightarrow \infty$) for the estimated decadal increases in trace gas abundances, with no climate feedbacks included. Formulas for $(\Delta T_e)_0$ as a function of the trace gas abundances are given by *Lacis et al.* [1981]. (*a*) Past additions. Except for O_3 and stratospheric H_2O, the estimated trace gas increases are based on measurements, as discussed in the text. (*b*) Future additions. Adopts case A scenario given in Table 10.

Senator WIRTH. Thank you very much. We have been joined by Senator Murkowski.

Senator Murkowski, do you have a statement?

Senator MURKOWSKI. No. I am interested very much in the witnesses' statements.

Senator WIRTH. OK. Dr. Blake?

STATEMENT OF DR. DONALD R. BLAKE, DEPARTMENT OF CHEMISTRY, UNIVERSITY OF CALIFORNIA, IRVINE, CA

Dr. BLAKE. Thank you very much.

Very recently, within the last two decades, the scientific community has become more and more interested in the changes that are being observed in the atmosphere, such as a general decrease in ozone levels over the northern hemisphere, whether at sea level rises, small temperature changes and most recently, the dramatic ozone depletion over the South Pole.

These are all tied together by the thin thread of increasing concentrations of gases in the atmosphere. I have been asked to participate in this primarily because I am one of the scientists who actually performs the analysis and comes up with these concentration versus time plots.

[Viewgraph.]

The first viewgraph, which I would like to have now, is probably the most recognizable plot of concentrations versus time of any atmospheric gas. This is carbon dioxide, and until very recently, this was about the only gas that was really considered to be much of a greenhouse forcing type of a gas. Jim will get into that a little bit later.

These are just a few of the gases that of are interest. They were shown on the last viewgraph, but this is a concentration versus time plot to try and impress upon you that in fact these increases are, in fact, real.

The top panel is difficult to read, and that is fluorocarbon 11. The next one is fluorocarbon 12, methyl chloroform tetrachloride and nitrous oxide, things that Dr. Ramanathan just spoke about.

This increase or this trend that we have observed, has gone on for at least the last 10 years. Things like fluorocarbon 11 which have a lifetime of on the order of 60 years, fluorocarbon 12 has a lifetime of about 100 or 110 years. These things float around for a long time.

It was just mentioned about the greenhouse effect and the ozone layer effect. I would like to emphasize that for just a minute. What we have to realize is that these species, once they are emitted into the atmosphere, float around and are greenhouse gases for up to 100 years or more and that is their sole function, so to speak, in the atmosphere. At which time for the long line of species that are the stratosphere, they absorb high energy solar radiation, energy that is of a high enough energy that it can actually rupture a carbon chlorine bond in the molecule.

Now, we go from a greenhouse problem to an ozone layer problem. Last week there was testimony that showed that in fact we are seeing a 1 to 5 or 6 percent decrease in total ozone over the northern hemisphere and certainly the South Pole data indicate a precipitous drop in ozone levels there. So, we sort of go from the frying pan into the fire as far as going from a greenhouse gas—once the greenhouse gas is not a problem anymore it is an ozone problem. I would say this is an artifact of having these long lifetimes.

The next viewgraph is data collected in our own research group. This is fluorocarbon 113, which is a recent addition to many atmospheric measurement systems and it is becoming a very important species in that it is increasing at a very fast rate, at about 10 percent in concentration per year. This is a greenhouse gas; it is also an ozone layer destroying gas.

My final viewgraph is the one that I would like to dwell on for a while. It has a number of interesting points about it. First, the methane record that we have goes back about 10 years. What we see is a very good linear correlation with an increase in methane of about 1 percent per year.

Spectral records show that in fact, this increase has gone back to the year 1951, that this 1 percent increase has continued since then. We see no sign of it decreasing. The interesting thing about methane is that number one, yes, it is a greenhouse gas. As was mentioned earlier, some of the sources are swamps and rice paddies.

Swamps and rice paddies are the ecosystem that produce the methane, the bacteria, have a very strong temperature dependence. So that by increasing the greenhouse effect forcing and essentially raising the surface temperatures by even a degree, can have an incredible effect on the actual production by these bacteria. In fact, a 1 degree change from 20 to 21 degrees celsius can effect methane production by as much as 20 or 30 percent. So, 1 degree can have a very large effect.

In turn, more methane is produced. There is more methane in the atmosphere and therefore, because there is more methane you have this positive feedback, you have more trapping by this greenhouse gas that is going on. So, methane is extremely important as far as the greenhouse gas.

Second, methane is very important because it deposits about 50 percent of all of the water vapor that is in the stratosphere. The reaction is that methane eventually floats up to the upper atmosphere, is oxidized, and eventually two water molecules are formed for every methane that is destroyed.

So, once we are rid of the methane in the upper atmosphere, now we have water which is in a stratosphere, is a greenhouse gas also. As I say, we get rid of the methane but now we have another greenhouse gas.

Perhaps more importantly, very recently the data from the South Pole indicate that polar stratospheric clouds play a significant role in the decrease in ozone in their austral spring. Polar stratospheric clouds are made up, in part, of water vapor. Therefore, the more water that we deposit into the stratosphere which is going up presumably at 1 percent per year, because that is what methane is going up at, the more we increase water vapor in the atmosphere and the stratosphere. We have more water that is condensible and can form polar stratospheric clouds, and we can provide more services not just at the south pole but potentially in other places where the temperatures are cold enough to increase the number and amount of polar stratospheric clouds which could then, depending upon the meteorology, go into participating in this depletion of the ozone layer.

So methane is an extremely important molecule, both as a greenhouse gas and as an ozone gas in that cycle.

What I would like to do just briefly is to, since I am not over there, explain how we go about collecting our data. I think that the rest of the scientists here today will be talking about these trends to try and impress upon you how we go about determining what these trends are.

Each of these data points that are on this plot represent a sample collection period for our research group. You notice that from about 1983 until 1987, the data points are extremely close together. We are funded by NASA at this time to essentially go from Barrow, Alaska to the tip of New Zealand and take samples at points in between. We do this every three months.

We send four members of our research group at Irvine out to these different places and we collect the samples, and then we bring them back and perform four different sets of analyses on these samples. And then, of these 60 to 80 samples that are collected we come up with a single point for the world average. Those are the points that are plotted here. So, these are not just individual samples. These represent between 60 and 80 actual collections that were distributed latitudinally throughout the world.

Finally, I mentioned lifetimes here, and I think that it is important to emphasize and maybe to explain what do we mean by an atmospheric lifetime and what impact does it have. I will admittedly use an extreme, but I think that it is worthwhile in this case.

If we use fluorocarbon 12, which has an accepted lifetime of about 100 years, if we could perform an experiment today wherein this room we took a cylinder of fluorocarbon 12 and somehow labeled it in a way that it would not alter it chemically as far as its chemical reactivity is concerned or its photochemical properties, so that once it filters up into the upper atmosphere it would react different or behave differently than it does now, if we could let that gas out into this room and 100 years from now have the ability to actually detect this in the atmosphere, with a 100 year lifetime, about 40 percent of that fluorocarbon 12 that we let go in this room today would still be in the atmosphere. A little more than 60 percent of it would be gone.

This is just by definition of what we mean by lifetime. So, it is important to realize that when we say that something has 100 year lifetime, it does not mean that it is completely removed from the atmosphere within 100 years. Some of it is removed in much less time than 100 years, but some of it is removed 200 or 300 years from now.

It is important to remember this. It is an average of 100 years for 60 percent of it to be gone. What that means is, if we continue to emit these long live species into the atmosphere at the rate that we are today and if we even stop today, we are guaranteeing the generation 100 years from now that they will have to deal with a greenhouse problem and an ozone layer problem.

Thank you.

[The prepared statement of Dr. Blake follows:]

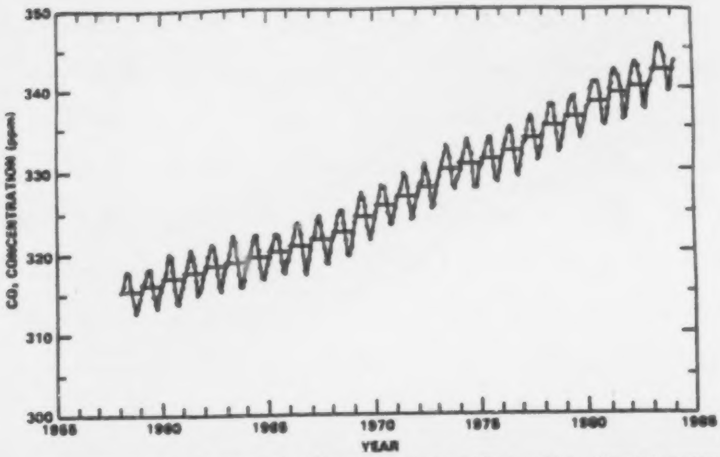
Testimony By Dr. Donald R. Blake, Department of Chemistry
University of California, Irvine, to the Senate Full Committee on
Energy and Natural Resources, Washington, D.C.
November 9, 1987

Our planet is continuously bathed in solar radiation. Although we who are confined to a fixed location on the globe experience day and night, the earth does not. It is always day in the sense that the sun is shining on half of the globe. Much of the incoming solar radiation, about 30 percent, is scattered back to space by clouds, atmospheric gases and particles, and objects on the earth. The remaining 70 percent is, therefore, absorbed mostly at the earth's surface. This absorbed radiation gives up its energy to whatever absorbed it, thereby causing its temperature to increase. Because solar radiation is absorbed continuously by the earth, it might be supposed that its temperature should continue to increase. It does not, of course, because the earth also emits radiation, the spectral distribution of which is quite different from that of the incoming solar radiation. The higher the earth's temperature, the more infrared radiation it emits. At a sufficiently high temperature, the total rate of emission of infrared radiation equals the rate of absorption of solar radiation. Radiative equilibrium has been achieved, although, it is a dynamic equilibrium: absorption and emission go on continuously at equal rates. The temperature at which this occurs is called the radiative equilibrium temperature of the earth. This is an average temperature, not the temperature at any one location or at any one time. It is merely the temperature that the earth, as a blackbody, must have in order to emit as much radiant energy as the earth absorbs solar energy.

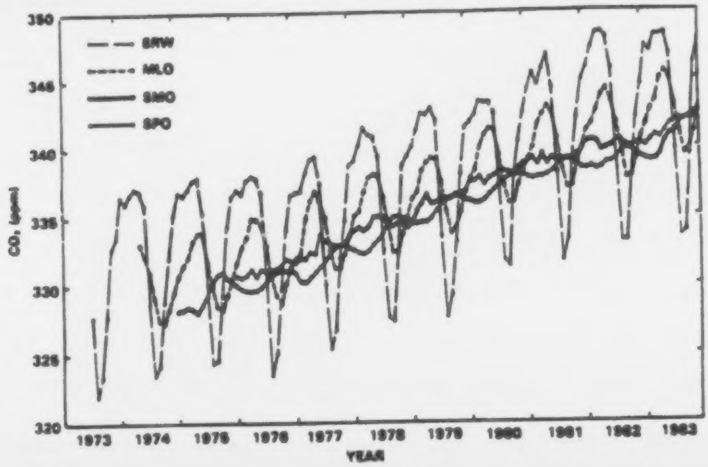
All objects emit radiation continuously, mostly in the infrared region. Some of this radiation is absorbed by the atmosphere, which makes it warmer than it would otherwise be. But the warmer the atmosphere the more it emits to the ground, hence, the ground is warmer than it would otherwise be. The extent to which the atmosphere absorbs infrared radiation is, therefore, of great importance in determining the temperature of the earth's surface. If the atmosphere absorbs no infrared radiation, the average surface temperature would be well below freezing, about 255 K (-18°C), and so would the air in contact with it. However, the atmosphere does absorb infrared radiation, and as a consequence surface temperatures are higher than they would otherwise be. This warming of the atmosphere and earth's surface has come to be known as the greenhouse effect.

Not all atmospheric gases absorb infrared radiation to the same degree. Indeed, the most abundant ones by far, nitrogen and oxygen, are the least absorbing. Of far greater importance are water vapor and much less abundant gases such as carbon dioxide (CO_2) and ozone (O_3). The atmospheric concentration of CO_2 is about 350 parts per million by volume (ppmv) and is increasing at a yearly rate of about one ppmv. A plot of the CO_2 concentration versus time is given in Figure 1. Fossil fuel combustion is the major source of carbon dioxide. About 60% of the carbon dioxide remains in the atmosphere while the rest is absorbed by the oceans or biosphere. Of major concern, is whether the oceans and biosphere can maintain pace with carbon dioxide production, thus, keeping the fraction at 60%. If not, the yearly increase in carbon dioxide will continue to rise.

Figure 1: Concentration versus Time



Concentration of atmospheric CO_2 at Mauna Loa Observatory, Hawaii, expressed as a mole fraction in ppm of dry air. The dots depict monthly averages of visually selected data which have been adjusted to the center of each month. The horizontal bars represent annual averages. Data obtained by C.D. Keeling, Scripps Institution of Oceanography, University of California, La Jolla, California, and are from files in the Carbon Dioxide Information Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee.



Provisionally selected montly mean CO_2 concentrations from continuous measurements at the NOAA/GMCC baseline observatories (:Barrow, Alaska (BRW); Mauna Loa, Hawaii (MLO); American Samoa (SMO); South Pole (SPO). Values are in the WMO X81 mole fraction scale (Harries and Nickerson, 1984).

One's first reaction about greenhouse contributions is that something like CCl_2F_2 (CFC-12), at levels of about 0.00045 ppmv and increasing annually at 0.00002 ppmv, would be trivial. However, as was previously mentioned, the greenhouse effect occurs through the absorption of infrared radiation into specific vibrational frequencies of polyatomic molecules in the atmosphere. Infrared radiation of the wavelengths, which can be absorbed by CO_2 vibrations, are already exposed to absorption by 350 ppmv of CO_2, and absorption by these vibrations is nearly saturated. Increasing the concentration to 351 ppmv will increase the probability of absorption a little, but it is hard to increase the total absorption very much if it is already 99.9%. On the other hand, the amounts of CFC-12, CFC-11 (CCl_3F), CFC-113 (CCl_2FCClF_2), methylchloroform (CH_3CCl_3), carbon tetrachloride (CCl_4), nitrous oxide (N_2O), and methane (CH_4) in the atmosphere are much smaller, and absorption in their vibrational frequencies is very far from saturation. Some of these absorptions happen to fall into infrared "windows", in which, absorption by H_2O, CO_2, and O_3 are all very weak or nonexistent, and the individual molecules can be as much as 10,000 times more effective in retaining infrared radiation than is the added CO_2 when the latter concentration is already about 350 ppmv. When you consider the effects from increasing concentrations of these halocarbons, N_2O, CH_4, and tropospheric O_3, etc., the combined absorptions from increments in these gases over the past decade become approximately as important as the increment in CO_2 in contributions to the anticipated overall greenhouse effect.

Increasing Concentrations of Selected Trace Gases

Trace gas concentrations in the atmosphere reflect, in part, the overall metabolism of the biosphere, and the broad range of human activities such as agriculture, production of industrial chemicals, and combustion of fossil fuels and biomass. There is dramatic evidence that the composition of the atmosphere is now changing, due to increased gaseous emissions associated with human activities.

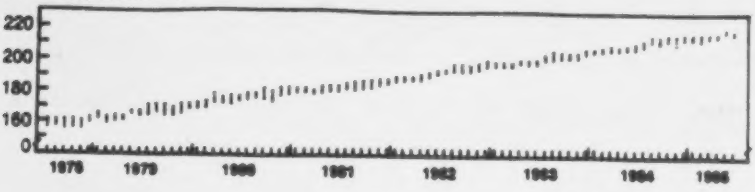
Detailed measurements of various halocarbons have been conducted since 1978, by a number of research groups throughout the United States. Although the absolute concentrations of individual species may vary by as much as 10% between research groups, there is generally good agreement concerning the overall trends.

Chlorofluorocarbons 12 and 11 are the most widely used CFCs at this time. They are globally used in many and varying applications some of which are as aerosol propellants, refrigerants, and foaming agents for plastics. Concentration versus time plots for these species are given in Figure 2. Both CFC-12 and CFC-11 are increasing at about 5% per year and are now found in the atmosphere at concentrations of about 450 parts per trillion by volume (pptv) and 250 pptv, respectively.

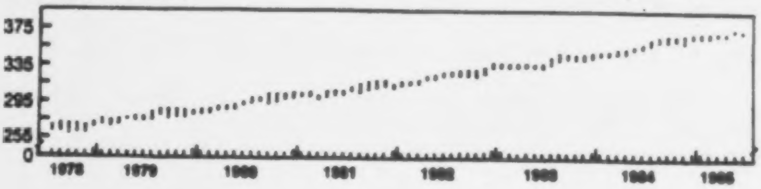
Carbon tetrachloride is used predominantly as a chemical intermediate in the production of CFCs 11 and 12, leading to relatively little emission of carbon tetrachloride to the atmosphere. A small fraction is still used as a solvent in chemical and pharmaceutical production processes. Uses as a grain fumigant is declining. The observed rate of increase is about 2%, while the current atmospheric concentration is about 130 pptv, Figure 2.

Figure 2: Concentration versus Time

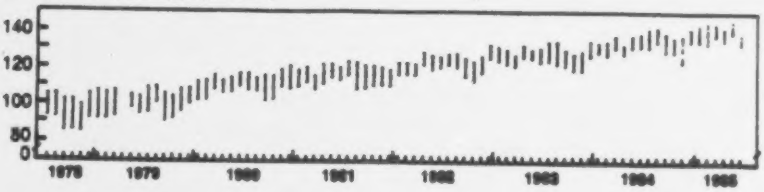
CFC-11, ppt (volume)



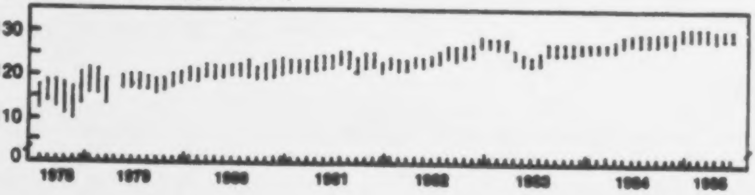
CFC-12, ppt (volume)



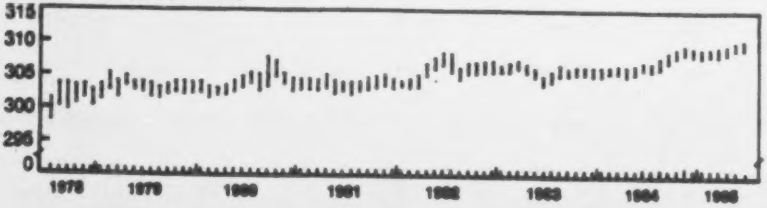
Methylchloroform, ppt (volume)



Carbon tetrachloride, ppt (volume)



Nitrous oxide, ppb (volume)

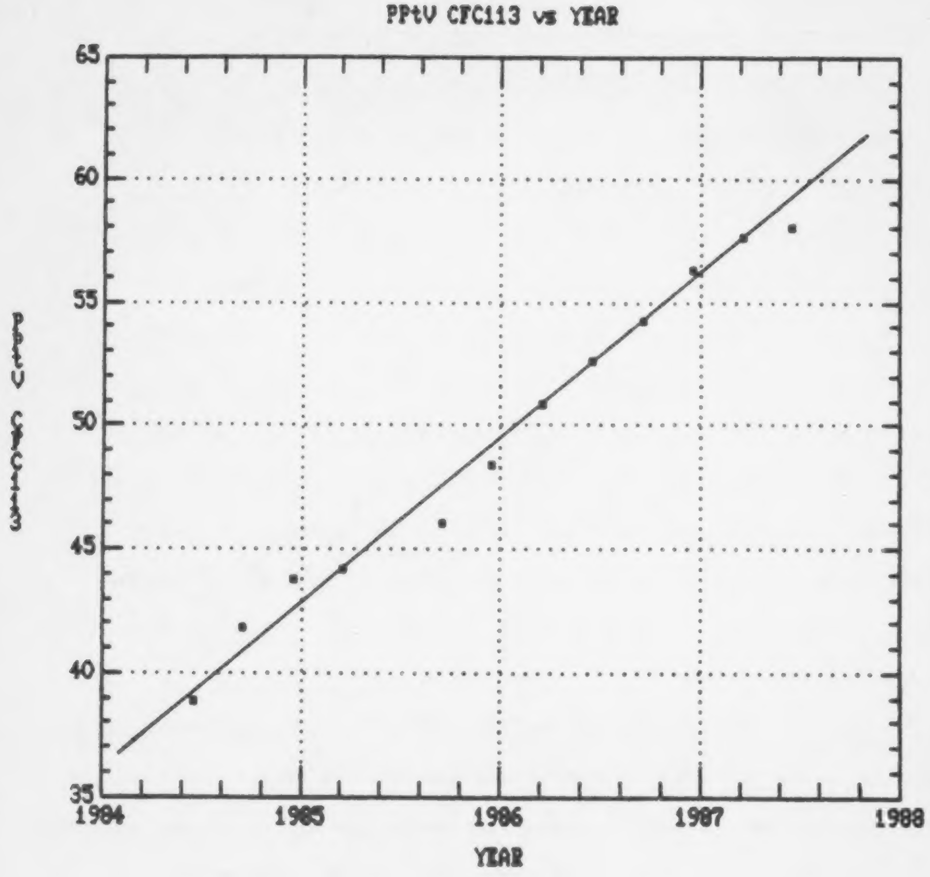


The trace gases trichlorofluoromethane (CFC-11, or $CFCl_3$), dichlorodifluoromethane (CFC-12, or CF_2Cl_2), methylchloroform (CH_3CCl_3), carbon tetrachloride (CCl_4), and nitrous oxide (N_2O) have been measured since mid-1978 at the Barbados station of the Global Atmospheric Gases Experiment (GAGE). The graphs show the monthly means and monthly variances there. Qualitatively similar results are obtained from the other GAGE stations located in Tasmania, Samoa, Oregon, and Ireland. At each station each of these trace gases is measured four or more times daily at ground level. Source: R. Prinn, P. Simmonds, F. Alyea, D. Cunnold, A. Crawford, P. Fraser, R. Rasmussen, and R. Rosen

Stabilized methylchloroform has been marketed since the early 1960's. Its principal use has always been the industrial degreasing of metallic or metaloplastic pieces. It is widely used for cold cleaning processes in the engineering industry. It is also used as a solvent in adhesives, varnishes, and paints where low flammability and low toxicity are important. Sales of methylchloroform grew rapidly in the 1960s and early 1970s, when it replaced tri- and perchloroethylene and carbon tetrachloride in many industrial applications. The atmospheric concentration of methylchloroform in 1987 is about 150 pptv and is increasing at about 7 pptv per year. Global emissions for methylchloroform are actually higher than that of CFC-12 yet the overall rate of increase is less. This reflects the difference in atmospheric lifetime between these two species, 110 years for CFC-12 and about 7 years for methylchloroform. The major removal process for methyl chloroform is by hydroxyl radical attack in the troposphere. The only known removal process for CFC-12 is photolysis in the upper stratosphere. The reason methylchloroform has a relatively short lifetime is due to its carbon-hydrogen bonds. Thus, if the currently used CFCs are replaced by compounds which contain a hydrogen bond, the atmospheric lifetimes will be greatly reduced.

The most recent addition to CFC monitoring among many research groups is that of CFC-113. This compound is used largely as a solvent to clean and deflux sophisticated electronic assemblies and components. Its future use is vulnerable to competing systems, changes in electronics technology, and possible requirements to reclaim the solvent. One can see from the concentration versus time plot given in Figure 3, that the large scale use of this particular species began

Figure 3: Concentration versus Time



about the time regulation of CFCs 11 and 12 began in this country. Although this is a difficult species to accurately measure, the atmospheric concentration is about 60 pptv and has a yearly increase of about 7 pptv.

Like the CFCs, nitrous oxide has a long lifetime, about 150 years, and is destroyed in the stratosphere. There nitrous oxide reacts with oxygen atoms to form nitric oxide, which can catalyze destruction of ozone. However, unlike the halocarbons, whose origins are unquestionably industrial, nitrous oxide has mostly natural sources. Humans may be increasing nitrous oxide emissions from soils by using ammonia and urea fertilizers. The added nitrogen eventually is returned to the atmosphere, partly as nitrous oxide. Burning coal which contains organic nitrogen compounds, is another anthropogenic source of nitrous oxide. The rate of increase observed for nitrous oxide is about 0.3% or 1 part per billion by volume (ppbv), Figure 2. Currently, atmospheric levels of nitrous oxide are at about 310 ppbv.

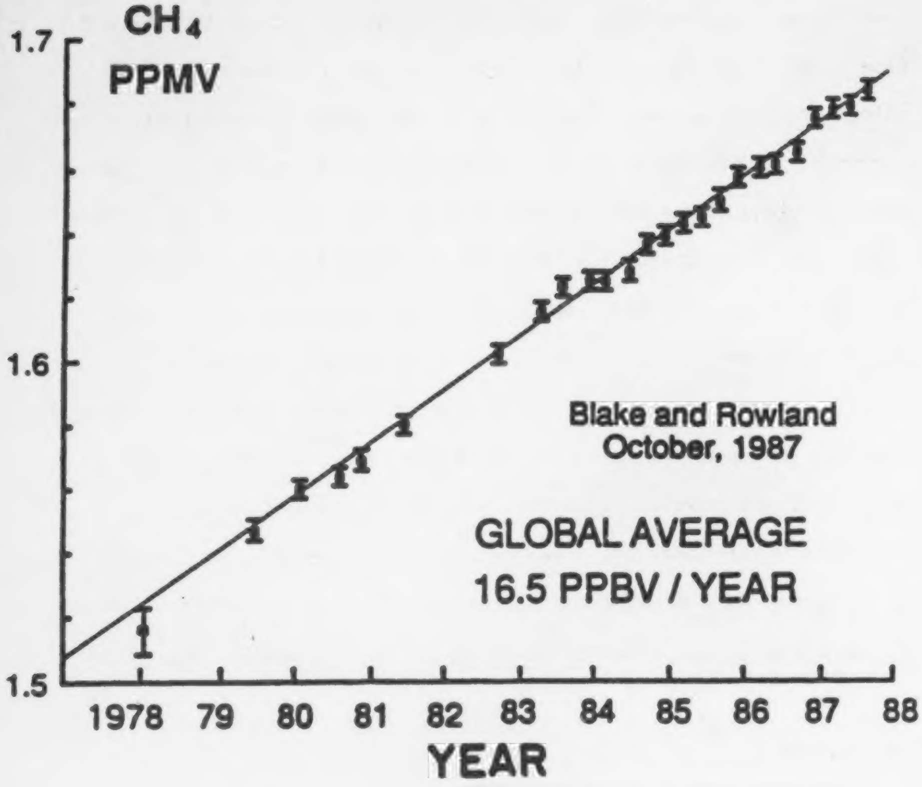
The final greenhouse gas to be discussed here is methane. Bacteria produce methane by anaerobic fermentation in wet locations where oxygen is scarce: swamps, peat bogs, other natural wetlands, paddies, and the intestinal tracts of cattle, sheep, and termites. Oil and natural gas exploitation also may be a significant source. Studies of the carbon-14 content of atmospheric methane indicate that at least 80% must have biological origin.

Increases in atmospheric methane could be due to the greater amount of area devoted to rice cultivation or the increased number of cattle. However, increases in atmospheric methane may also be caused by rising levels of carbon monoxide from combustion processes. Both methane and carbon monoxide are removed from the atmosphere largely by reaction with hydroxyl radicals. With both gases competing for a limited amount of hydroxyl, the average lifetime of a methane molecule before it is destroyed may be getting longer. A plot of the methane concentration versus time is given in Figure 4. The current world average concentration of atmospheric methane is 1.685 ppmv, while the steady yearly increase observed is about 0.016 ppmv, or about 1%.

The major removal of atmospheric methane occurs in the troposphere, however, about 10% drifts up into the stratosphere. Once there, the methane is oxidized during which water molecules are formed. Two important routes exist for depositing water vapor into the stratosphere. The first is simply being carried upward as water rising in air; the second involves carrying hydrogen atoms upward in the chemical form of methane, and then releasing them as the methane molecule is oxidized. In the 1980s atmosphere, these two processes deliver approximately equal amounts of hydrogen to the stratosphere. However, with atmospheric methane concentrations increasing at a rate of about 1% per year, the average amount of water vapor in the stratosphere is presumably steadily increasing with time. An increase in stratospheric water vapor has a binary effect. Water itself is a greenhouse gas and, thus, increasing stratospheric water vapor levels will add to the overall global warming. Secondly, the more water vapor in the stratosphere, the more water there is available to form polar stratospheric clouds, which have been linked to the dramatic losses in ozone over Antarctica during austral spring.

All of the CFCs are not only very efficient at absorbing terrestrial infrared radiation but also play a major role in

Figure 4: Concentration versus Time



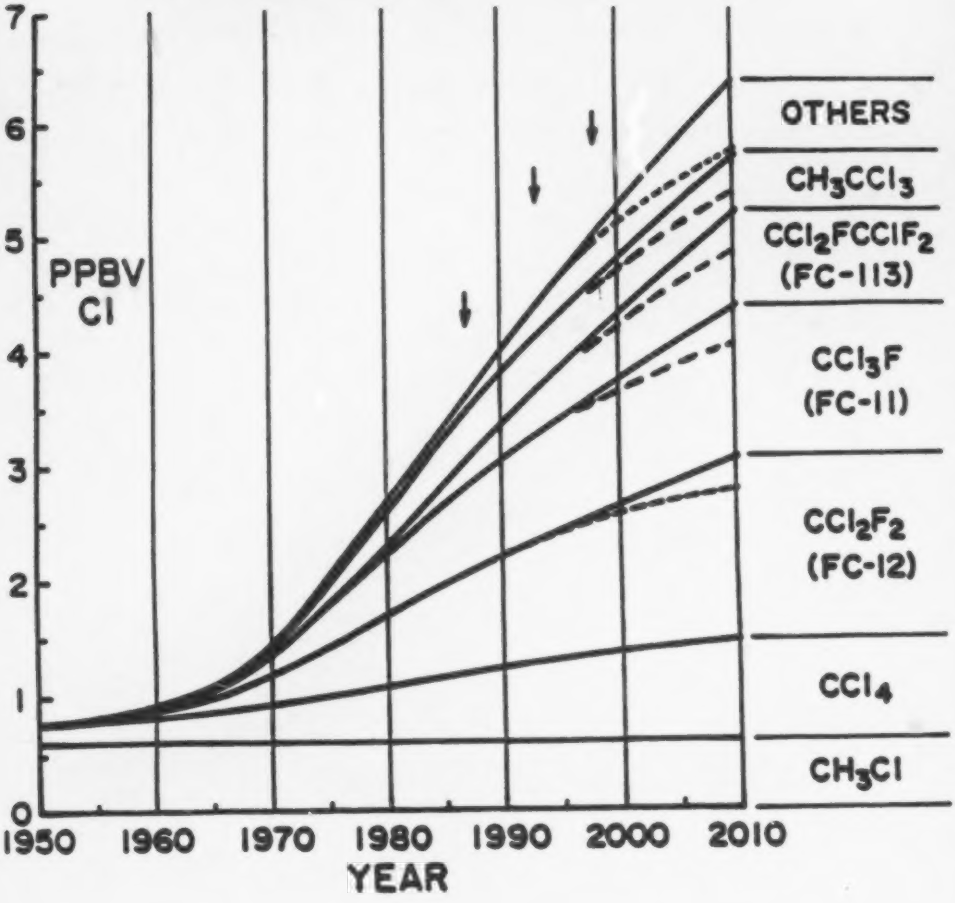
GROWTH IN TROPOSPHERIC MIXING RATIO OF METHANE transporting chlorine atoms into the stratosphere where they can participate in the catalytic destruction of the ozone layer. All of these gases have very long atmospheric lifetimes, about 110 years for CFCs 12 and 113, 75 years for CFC-11, and about 50 years for the chlorocarbon CCl_4. What this means is that these species drift around until they reach the upper stratosphere. During this lengthy journey, these compounds have been absorbing outgoing radiation being emitted by the earth and redirecting a large portion back towards the ground. Once these gases are high enough in the stratosphere they undergo another absorption, but this time it is with solar ultraviolet radiation, during which a chlorine atom is ejected from the remaining radical. At this point in time we switch from a greenhouse problem to an ozone layer problem. However, because of the extremely long atmospheric lifetimes for these halocarbons, they will have contributed to the greenhouse warming for decades or even centuries before their chlorine begins the catalytic dedtruction of the ozone layer.

Conclusions

Carbon dioxide, halocarbons, nitrous oxide, methane, and many more trace gases not mentioned here, are all greenhouse gases that can lead to global warming. This warming is not just a theory but reality waiting to happen. These gases also play a major role in determining stratospheric ozone levels. With the unprecedented decrease in ozone above Antarctica in austral spring and recent statistical ozone studies indicating a decrease in northern hemisphere ozone levels by as much as 3%, it is not just a theory anymore. The gases that affect these two phenomena are rapidly increasing in atmospheric concentrations due, in part, to the extremely long lifetime of these species. At this point in time, there is no indication from the data being collected, that the rate of increase for these gases will decline significantly before the end of the century, Figure 5. The already mentioned long lifetime of some of these gases means that even if all emissions to the atmosphere were completely halted today, many of these species would still be having an affect hundreds of years from now, on global warming and the catalytic destruction of the ozone layer.

Figure 5: Halocarbons versus Time

EXPECTED GROWTH IN ORGANOCHLORINE CONCENTRATIONS IN THE ATMOSPHERE. SOLID LINE INDICATES PAST GROWTH, AND EXPECTED FUTURE GROWTH IF THE YEARLY EMISSIONS OF THE CHLOROFLUOROCARBONS REMAIN CONSTANT AT THE 1986 LEVELS. DASHED LINES INDICATE THE EXPECTED FUTURE GROWTH IF THE EMISSIONS ARE REDUCED BY 20% in 1994 AND BY 50% IN 1999. ARROWS INDICATE THE PRESENT TIME, AND THE TIME OF EACH OF THE TWO CUT-BACKS OUTLINED IN THE MONTREAL PROTOCOL OF SEPTEMBER 1987.



Senator **Wirth**. Thank you, Dr. Blake.

Dr. Hansen.

STATEMENT OF DR. JAMES E. HANSEN, ATMOSPHERIC SCIENTIST, NEW YORK, NY

Dr. **Hansen**. Senator Wirth and Senator Murkowski, thank you for the opportunity for me to testify. Before I begin, I would like to state that although I direct the NASA/Goddard Institute for Space Studies, I am appearing here as a private citizen on the basis of my scientific credentials.

The views that I present are not meant to represent in any way agency or administration policy. My scientific credentials include more than 10 years experience in terrestrial climate studies and more than 10 years experience in the exploration and study of other planetary atmospheres.

I will summarize the result of numerical simulations of the greenhouse effect, carried out with colleagues at the Goddard Institute. Previous climate modeling studies at other laboratories and at our own examined the case of doubled carbon dioxide, which is relevant to perhaps the middle of the next century based on expected use of fossil fuels.

The unique aspect of our current studies is that we let CO_2 and other trace gases increase year by year as they have been observed in the past 30 years, and as projected in the next 30 years. This allows us to predict how climate will change in the near term, and to examine the question of when the greenhouse effect will be apparent to the man in the street.

[Viewgraph.]

We began our climate simulation in 1958 when CO_2 began to be measured accurately, as shown on the first viewgraph. Measurements of other trace gases such as methane, chlorofluorocarbons and nitrous oxide began more recently, but their trends can be estimated with reasonable accuracy back to 1958.

For the future, it is difficult to predict reliably how trace gases will continue to change. In fact, it would be useful to know the climatic consequences of alternative scenarios. So we have considered three scenarios for future trace gas growth, shown on the next viewgraph.

Scenario A assumes the CO_2 emissions will grow 1.5 percent per year and that CFC emissions will grow 3 percent per year. Scenario B assumes constant future emissions. If populations increase, Scenario B requires emissions per capita to decrease.

Scenario C has drastic cuts in emissions by the year 2000, with CFC emissions eliminated entirely and other trace gas emissions reduced to a level where they just balance their sinks.

These scenarios are designed specifically to cover a very broad range of cases. If I were forced to choose one of these as most plausible, I would say Scenario B. My guess is that the world is now probably following a course that will take it somewhere between A and B.

We have used these three scenarios in our global climate model, which simulates the global distribution of temperatures, winds, and other climate parameters. Running our model from 1958 to the year 2030, the results for the global mean temperature are as shown in the next viewgraph. The model yields warming by a few tenths of a degree between 1958 and today. In fact, the real world shown by the black curve, has warmed by something of that order.

This warming is not large enough relative to the natural variability of climate, for us to claim that it represents confirmation of the model. But we may not have long to wait if warming of 0.04 of a degree centigrade which is three times the standard deviation of the natural variability of the global temperature, if that is maintained for several years that will represent strong evidence that the greenhouse effect is on this track.

If the world follows trace gas Scenario A or B or something in between, the model says that within 20 years global mean temperature will rise above the levels of the last two interglacial periods and the earth will be warmer than it has been in the past few hundred thousand years.

The man in the street is not too concerned about global mean, annual mean temperature, so let us look at maps of the predicted temperature change for a particular month.

The next viewgraph shows the computed temperature anomalies for July for the intermediate Scenario B. This shows July, 1986 in the upper left, going to July of 1987, 1990 and then on the right, 2000, 2015 and 2029. The yellows and reds are the areas that are significantly warmer than the 1950's climatology. Blues are areas that are colder than normal.

The map, for any given month, represents natural fluctuations or noise of the climate system as well as a long term trend due to the greenhouse effect.

The natural fluctuations are an unpredictable sloshing around of a nonlinear fluid dynamical system. So, these maps should not be taken as predictions of the precise patterns for a particular year.

One conclusion that I want to draw from these maps is that at the present time in the 1980's in a given month, there are almost as many areas colder than normal as areas warmer than normal. This is because the greenhouse warming is smaller than the natural fluctuation of regional climate.

You can see that by 13 years from now, the year 2000, the probability of being warmer than normal is much greater than being cooler than normal. In a few decades from now, it is warm almost everywhere.

So, how important are temperature anomalies of this magnitude? One indication is provided by recent experience in the real world. The next viewgraph shows observational data for July 1986 on the top and July, 1987 on the bottom.

You probably remember that in July of 1986 there was a heat wave in the Southeast United States, and in July of 1987 it was warm on the east coast. The same color scale is used here as for the model results, so you can use the last two July's in the real world to gage the yellow and red colors in the preceding maps.

This makes it obvious that the model predictions for the future shown on the earlier graph represent a major increase in the frequency and severity of July heat waves.

In the letter requesting my testimony, you asked me specifically to address the question of how the greenhouse effect may modify the temperatures in the Nation's city. The next viewgraph shows estimates of the number of days per year in which the temperature exceeds a given threshold.

For example for Washington, DC, the number of days in which the temperature exceeds 100 degrees fahrenheit has been one day per year on the average in the period 1950 to 1983. In the doubled CO_2 climate, which will be relevant to the middle of the next century if the world follows trace gas Scenario A, there are about 12 days per year above 100 degrees fahrenheit.

The number of days per year with temperature exceeding 90 degrees fahrenheit increases from about 35 to 85, and the number of nights in which the minimum does not drop below 80 degrees fahrenheit increases from less than one per year to about 20 per year in our climate model.

Obviously, if the greenhouse effect develops to this extent, it will have major impacts on people. The doubled CO_2 level of climate change is not expected until, perhaps the middle of the next century. It is difficult to predict when, because it depends upon which emission scenario the world follows.

Predictions for the more immediate future are shown on the next viewgraph. This shows the number of days with temperatures exceeding 90 degrees fahrenheit decade by decade. Climatology is the 1950's through the 1970's. The results for Scenario A, which we described as business as usual are on the left.

Scenario C on the right, has drastic and probably implausible emission cuts. The conclusion that I draw from this graph is that climate impacts depend greatly on the emission scenario which the world follows.

The climate impacts in Scenario A become dramatic by the 2030's, but in Scenario C, the mean effect remains smaller than the year to year natural variability.

Finally, I would like to comment on an obvious question: How good are these climate predictions? The climate models we employ and our understanding of the greenhouse effect have been extensively tested by simulations of a range of climates which existed at past times on the earth and on other planets.

So, we know the capabilities and limitations of the global models reasonably well. There is, in fact, a substantial range of uncertainty in the predicted temperature change. For example, we can only say that the global climate sensitivity, the doubled CO_2, is somewhere in the range from 2 degrees centigrade to 5 degrees centigrade.

The model used in our studies has a sensitivity of 4 degrees centigrade, which is in the middle of the range obtained from other global climate models.

The geographical patterns of greenhouse climate effects are uncertain, especially changes in precipitation, as Dr. Manabe will discuss. However, the uncertainties in the nature and patterns of climate effects cannot be used as a basis for claiming that there may not be large climate changes.

The scientific evidence for the greenhouse effect is overwhelming. The greenhouse effect is real, it is coming soon, and it will have major effects on all peoples. As greenhouse effects become apparent, people are going to ask practical questions and want quantitative answers. Before we can provide climate projections with the specificity and the precision that everyone would like, we first must have major improvements in our observations and understanding of the climate system.

In my submitted testimony, I have listed observations which I believe are most crucial. I believe it is very important that observational systems be in place by the 1990's as greenhouse effects become significant. That is necessary if we are to be able to provide decision-makers and improved information as the greenhouse effect grows, and its importance to society.

Thank you for this opportunity to express my opinion.

[The prepared statement of Dr. Hansen follows:]

PREDICTION OF NEAR-TERM CLIMATE EVOLUTION:
WHAT CAN WE TELL DECISION-MAKERS NOW?

STATEMENT OF:

James E. Hansen
33 North Pleasant Avenue
Ridgewood, NJ 07450

PRESENTED TO:

United States Senate

Committee on Energy and Natural Resources

November 9, 1987

Mr. Chairman, thank you for inviting me to testify before the Senate Committee on Energy and Natural Resources. My testimony today is in response to your letter of November 2, 1987, which requested my "views on the likely pace and regional implications of the greenhouse effect and global climate change, with specific reference to temperature changes in the nation's cities." I am appearing today as an expert on global climate and global change, based on my experience of more than 10 years in terrestrial climate studies and more than 10 years in the exploration and study of other planetary atmospheres. Although I direct the NASA Goddard Institute for Space Studies, I am appearing on the basis of my scientific credentials; the views that I present are not meant to represent in any way agency or administration policy.

My testimony will be in part a review of existing scientific knowledge about the greenhouse effect and in part a description of current climate model research at the Goddard Institute for Space Studies in which my colleagues (I. Fung, A. Lacis, S. Lebedeff, D. Rind, R. Ruedy, G. Russell, P. Stone) and I have simulated the unfolding of greenhouse climate effects during the next 10-30 years. Previous simulations of greenhouse effects have been confined to the case of doubled carbon dioxide, relevent to the middle of the 21st century; thus I must rely on the current results from the GISS model for discussion of climate trends during the near-term. I will confine my discussion to temperature changes. Dr. Manabe will testify about impacts of the greenhouse effect on precipitation and soil moisture.

I hope that in my presentation I can find an appropriate middle ground between the preference of scientists to stress all caveats in detail, and the desire of non-technical parties for an understandable practical statement of the status of scientific understanding.

1. Are Major Greenhouse Climate Changes a Certainty?

Our understanding of the greenhouse effect is based on a broad range of evidence, both theoretical and empirical. Global climate models or general circulation models (GCMs), which are mathematical representations of the atmosphere and ocean used to simulate weather and climate change on large scale computers, suggest that a doubling of atmospheric carbon dioxide will cause a global mean warming of somewhere between 2.5° and 5.5°C. Results from all the GCMs are thus consistent within about a factor of two.

Empirical evidence about climate sensitivity is more important, in my opinion, and it is consistent with the climate model results. Principal empirical evidence is summarized in Fig. 1. The inner planets Venus, Earth and Mars have a broad range of greenhouse gas abundances; Venus has a very thick CO_2 atmosphere, the earth's atmosphere is of intermediate thickness, and Mars has a thin CO_2 atmosphere. Each of these planets is warmer than it would be without an atmosphere, given their distances from the sun. Venus has a greenhouse effect of several hundred degrees, the earth is 33°C warmer than it would be without its greenhouse gases, and Mars has a greenhouse effect of only a few degrees. The observed temperatures are consistent with the theoretical expectations for the observed atmospheric composition on each planet.

Remarkable confirmation of our understanding of climate sensitivity has been developed in the 1980's from paleoclimate records, the principal advance being accurate determination of fluctuations in atmospheric CO_2 during the past 100,000 years. Although scientists continue to debate why CO_2 changed, a great deal of information is available on how CO_2 and other climate parameters (such as land ice, sea ice cover, vegetation distribution, and earth orbital parameters) differed between ice ages and interglacial periods. This allows quantification of the contribution of different processes to a well documented large global climate change. The important result is empirical evidence for an equilibrium climate sensitivity of about 2.5-5°C for doubled CO_2, consistent with the sensitivity of global climate models.

Additional empirical evidence is provided by the observed global warming of about 0.6°C in the past century. This is consistent with the expected warming due to known increases of atmospheric CO_2 and trace gases in that period. This empirical evidence does not provide as precise a measure of climate sensitivity as we might hope, because part of the warming due to increased greenhouse gases is delayed due to the thermal inertia of the oceans; the delay is greater if climate sensitivity is greater, so the short-term temperature rise is not so different between cases of low and high climate sensitivity. This ambiguity could be removed if we measured accurately the rate of heat storage in the ocean. At this time we can only say that the observed warming in the past century is consistent with any climate sensitivity in the range 2-5°C for doubled CO_2.

Conclusion: in view of the facts that (1) even conservative projections of CO_2 and trace gas growth indicate an equivalent doubling of CO_2 by the second half of next century, and (2) the warmest time in the past 100,000 years was only about 1°C warmer than today (cf. Fig. 2), we can confidently state that major greenhouse climate changes are a certainty. However, as shown by results below for different trace gas scenarios, the impacts are much less in scenarios with reduced trace gas growth rates.

2. Can we predict greenhouse climate changes that will occur in the near-term, say in the next 10-30 years?

Prediction of near-term climate trends, as opposed to equilibrium doubled CO_2 climate changes, introduces several major complications. First, we must give up the luxury of using an arbitrarily fixed CO_2 change, and instead consider how CO_2 and trace gas abundances might evolve in the real world. Second, instead of solving for an equilibrium response relevant to some poorly specified far-future date, we must tackle the time-dependent response of the climate system; that means we must account for the ocean's role in climate change, since the ocean is the principal source of thermal inertia in the climate system. Third, because near-term greenhouse climate effects are small compared to those for doubled CO2, we must be concerned about other climate forcings which may be comparable to greenhouse gases, and we must compare predicted climate changes to natural variability of the system.

Trace gas scenarios. CO_2 and other trace gas abundances are reasonably well known for the period since 1958, when CO_2 began to be monitored accurately, as illustrated in Fig. 3. Although it is very difficult to predict future trends, our objective is to consider a broad range of scenarios to help evaluate the implications of different alternatives. The three scenarios we employ (Fig. 4) are:

Scenario A - continued growth of emissions at rates which are compounded annually, and thus are exponential; e.g., CO_2 emissions increase 1½%/year and CFC emissions increase 3%/year.

Scenario B - fixed annual growth of greenhouse forcing; if population grows, this scenario implies a reduction in per capita emissions.

Scenario C - greenhouse forcing ceases to increase after year 2000; CFC emissions are terminated by 2000 and other trace gas emissions just balance their sinks; this would require drastic cuts in fossil fuel use, perhaps half of the current use.

In view of resource constraints and environmental concerns, Scenario A must eventually yield unrealistically large greenhouse forcing. Scenario C, on the other hand, represents a more drastic curbing of emissions than usually has been contemplated. Scenario B is probably the most plausible of the three scenarios.

Transient ocean response. The time dependent response of the climate system to changes of climate forcing depends principally upon the ocean. Unfortunately, capabilities for modeling the global ocean are much more primitive than capabilities for modeling the atmosphere. As a result, for the climate simulations which we present here we make a gross simplifying assumption about ocean heat transports: we assume (1) that for the next few decades the pattern of horizontal heat transport by ocean currents will remain the same as it is today, and (2) heat perturbations penetrate the deep ocean at a rate based on observed penetration of inert tracers (such as tritium sprinkled on the ocean in nuclear testing).

Although these assumptions are plausible for small climate perturbations, it must be recognized that we are thereby forcing the ocean to be relatively surprise-free. In the real-world, climate changes at the ocean surface may induce changes in ocean heat transports, thus leading to other, perhaps larger, climate changes. Broecker, for example, has stressed the possibility of changes in Gulf Stream and related ocean transports. Especially because of these assumptions about the ocean, it is unlikely that we can predict regional climate surprises; this is somewhat analogous to the difficulty that atmospheric chemistry models have in predicting or simulating post facto the Antarctic ozone hole.

Other climate forcings. At the present time the climate forcing due to increasing greenhouse gases is not large enough to completely dominate other global climate forcings such as changes of atmospheric aerosols or changes of solar irradiance (Fig. 5). For example, the solar irradiance was observed to decrease by ~ 0.09% between 1979 and 1985, which represents a somewhat larger forcing (of the opposite sign) than the forcing due to the atmospheric CO_2 increase in the same period. An even larger global climate forcing occurred in the period 1982-84 due to stratospheric aerosols generated by the volcano El Chichon (Fig. 5, lower panel), which would tend to cause a global cooling for at least that period.

Climate forcings such as changes in solar irradiance and stratospheric aerosols increase and decrease with time, and thus eventually are overwhelmed by monotonically increasing greenhouse gases. But on the time scale of a decade or so, the climate effects of these other forcings may be noticeable and impact our ability to detect the greenhouse effect. In our climate simulations we include the climate forcing due to stratospheric aerosols; we employ available measurements of aerosol opacity for the period 1958 to the present and we examine the impact of alternative assumptions for the level of future volcanic activity. We do not include variations of solar irradiance, because measurements are only available for the past several years. It is important that these climate forcings continue to be monitored to allow interpretation of current and future climate trends.

Conclusion: We can simulate greenhouse climate effects for assumed future trace gas scenarios, but, in addition to being aware of the uncertainty in climate sensitivity, which was discussed above, we must recognize the implications of simplifying assumptions about the ocean. Moreover, the impact of other climate forcings can be comparable to the greenhouse effect in the near-term. Finally, predicted greenhouse climate effects must be compared with the magnitude of unforced climate fluctuations.

3. Simulations of Near-Term Climate Change.

We present here sample results from the transient climate change simulations with the GISS GCM. This GCM, schematically illustrated in Fig. 6, has been documented elsewhere (Mon. Wea. Rev., 111, 609-662, 1983; AGU Geophys. Mono. 29, 130-163, 1984). The principal characteristics affecting the simulations reported here are:

Global sensitivity: the model has a sensitivity of about 4°C for doubled CO_2; ocean transports: horizontal transport by ocean currents is specified, based on estimates for today's ocean; uptake of heat perturbations by the deep ocean is mimicked as a diffusive process dependent on local stability of the water column, calibrated by measurements of transient tracers; trace gas growth: scenarios employed are illustrated in Fig. 4; stratospheric aerosols: observed trends are used for the period 1958-1985, which included large volcanic injections by Mt. Agung in 1963 and El Chichon in 1982; scenario A assumes that near-term future volcanic aerosols will be negligible, as was the case in 1915-1960; scenarios B and C assume a volcanically active future, as in the period 1958-1985, by inserting large volcanoes in 1995, 2015, 2025; other climate forcings: no changes of solar irradiance or other climate forcings are included.

The computed global mean temperature trends for scenarios A, B and C are illustrated and compared with observations in Fig. 7. Interpretation of Fig. 7 requires quantification of the magnitude of natural variability, in both the model and observations, and the uncertainty in the measurements. The standard deviation of the model's global mean temperature is about 0.1°C. The standard deviation about the 100 year mean for the observed surface air temperature trend of the past century (which has a strong trend) is 0.20°C; it is 0.12°C after detrending (Science, 214, 957-966, 1981). It is not surprising that the variability of the observed global temperature exceeds the variability in the GCM control run, since the latter contains no variable climate forcings such as changes of atmospheric composition or solar irradiance. Finally, we note that the one-sigma error in the observations due to incomplete coverage of stations is about 0.05°C for the period 1958-1985 (Hansen and Lebedeff, J. Geophys. Res., in press), which does not contribute appreciably to the 0.12°C variability (standard deviation) of the observed global temperature. We conclude that a warming of about 0.4°C is required to be significant at the 3σ level (99% confidence level).

There is no clearly significant warming trend in either the model or observations for the period 1958-1985. During the single year 1981 the observed temperature nearly reached the 0.4°C level of warming, but by 1985 the observed temperature was no greater than in 1958.

The model predicts, however, that by the late 1990's the global temperature will reach and maintain a 3σ level of global warming, which is clearly significant. Although this conclusion depends upon certain assumptions, such as the climate sensitivity of the model and the absence of large volcanic eruptions in the next few years, it is robust for a very broad range of assumptions about CO_2 and trace gas trends, as illustrated in Fig. 7.

Another conclusion is that global warming to the level attained at the peak of the current interglacial and the previous interglacial is inevitable; even with the drastic, and probably unrealistic, reductions of greenhouse forcings in scenario C, a warming of 0.5°C is attained within the next 15 years. The eventual warming in this scenario would exceed 1°C, based on the forcing illustrated in Fig. 2 and the climate sensitivity of our GCM. The 1°C level of warming is exceeded during the next few decades in both scenarios A and B; in scenario A that level of warming is reached in less than 20 years and in scenario B it is reached within the next 25 years.

The geographical distribution of the predicted surface air temperature change for the intermediate scenario B is illustrated in the left column of Fig. 8 for the 1980's, the 1990's and 2010's. The right column is the ratio of this decadal temperature change to the interannual variability (standard deviation) of the local temperature in the 100 year control run of the GCM. Since the interannual variability of surface air temperature in the model is reasonably similar to the variability in the real world, this ratio provides a practical measure of when the predicted mean greenhouse warming is locally significant.

Averaged over the full decade of the 1980's, the model indicates a tendency toward warming, but in most regions the decadal-mean warming is less than the interannual variability of the annual mean. In the 1990's the decadal-mean warming is comparable to the interannual variability for many regions, and by the 2010's essentially the entire globe has very substantial warming, as much as several times the interannual variability of the annual mean.

The man-in-the-street is more likely to notice whether the monthly mean climate is hotter or colder than normal, rather than changes of decadal mean temperature. Thus in Fig. 9 we illustrate maps of computed temperature anomalies for a particular month (July) in several different years. These maps illustrate that when the temperature is averaged over a period as short as one month, there are in the 1980's about as many areas colder than normal as warmer than normal. A noticeable trend toward warming occurs within 10-15 years, illustrated by model results for 2000, but at that time there are still many areas with monthly mean-temperatures colder than normal. However, after a few decades, the great majority of regions are significantly warmer than normal in any given month.

We stress that temperature maps for any given month and year represent natural fluctuations (noise) of the climate system as well as some long-term trend due to greenhouse forcing of the climate system. The natural fluctuations are an unpredictable "sloshing around" of a nonlinear fluid dynamical system.

Thus the maps for a specific month and year should not be taken as a prediction of detailed temperature anomaly patterns for that particular year.

It is fair, however, to examine the maps for consistent patterns and trends which can be related to physical mechanisms. For example, the warming is generally greater over continental areas than over the ocean, and greater at high latitudes than at low latitudes. The first result is expected because the oceans respond more slowly than the continents to the greenhouse heating, as a result of the ocean's large heat capacity. The surface warming in the model is greater at high latitudes than at low latitudes, because of the greater stability of the atmosphere at high latitudes and the positive sea ice/albedo feedback there.

We also note a tendency for the computed warming in the 1980's and the 1990's to be relatively greater than average over the U.S. southeast and less over the western United States and parts of Europe. Changes in sea level pressure patterns associated with ocean areas which warmed relatively little may provide a mechanism for such a tendency. However, very different patterns occur in some years. Moreover, it should be remembered that ocean heat transports were fixed in our model; changes in ocean transports could greatly modify the geographical patterns of temperature change.

Conclusion: The climate model results indicate that greenhouse effects on near-term global temperature trends should be apparent within the next several years. The computed greenhouse warming remains smaller than the natural variability of regional monthly mean temperature for the next decade or two, but a tendency for more warm areas than cool areas becomes apparent in the model by the 1990's.

4. Observed Climate Trends.

Estimates of surface air temperature trends are based on measurements recorded at about 2000 meteorological stations which are very unevenly distributed over the globe. The uncertainties in the inferred global temperature trend are investigated quantitatively in attachment A (cf. p. 11), which will be published in the Journal of Geophysical research in November 1987. The graphs presented here are derived from that publication, but we emphasize that our results are consistent with those of other researchers (such as Wigley, Jones and others at the University of East Anglia, and J. Angell of Air Resources Laboratory, NOAA) for the common periods of analysis.

Observed surface air temperature anomalies for the first seven years of the 1980's are illustrated in Fig. 10a. There is evidence of warming in the observations, and the locations of greatest warming, in Asia and at high latitudes, are not inconsistent with the model simulation (Fig. 8). As indicated by Fig. 8, a much more conclusive comparison of the model and observations will be possible by the 1990's.

The temperature data available for 1987 is shown in Fig. 10b. For the available months, 1987 is a remarkably warm year, indeed the warmest in the history of recording instruments. North America is particularly warm, with some areas more than 3°C above 1951-1980 climatology, while Europe is relatively cool. Low latitudes are very warm, which undoubtedly is a result of the El Nino which has been taking place during 1987. An El Nino involves the spreading of warm surface waters over certain low latitude ocean regions which normally have upwelling cold deep water; the phenomenon occurs aperiodically at intervals of about 2-5 years and tends to result in warming of the entire tropical troposphere.

As stressed in Section 3, monthly mean temperature anomalies are of great practical importance. Observations for July 1986 and July 1987 are shown in Fig. 11. Fig. 11 illustrates, for example, that the Southeast U.S. was warm in July 1986 and the entire eastern seaboard of the U.S. was warm in July 1987. In both of these years there are about as many midlatitude regions which are colder than normal as there are regions warmer than normal.

One reason we have illustrated observations for specific months is that it allows a calibration of the magnitude of regional anomalies which we have recently experienced, such as the warm Julys in the Southeast and on the eastern seaboard of the United States. Since the same color scale was used for the model simulations in Fig. 9, it is apparent that the model predictions for future decades represent a substantial increase in the frequency of such warm events as well as a substantial increase in the severity of the warmest events.

The global temperature trend for the past century, including the partial result for 1987, is shown in Fig. 12. The earth's temperature increased by 0.5°C between the 1880's and 1960, decreased by 0.2°C between 1940 and 1965, and has increased at a rapid rate since 1965. An estimate of the rate of the current warming trend depends considerably on whether the temperature in the next few years remains near the 1987 level. Indeed, at least a temporary decrease from the 1987 level should be anticipated, in view of the probable contribution of the current El Nino to the 1987 global temperature.

Conclusion: Observations indicate a strong warming trend from the mid 1960's to the present. The global temperature in the 1980's is at the highest level in the history of recorded measurements, despite recent trends of solar irradiance and stratospheric aerosols which tend to cool the earth's surface. We conclude that there is strong evidence for an underlying warming trend, but a definitive association with the greenhouse effect requires further data and studies as described in the final section below.

5. Climate Impacts: Will the Temperature Changes Be Significant to the Man-in-the-Street?

The global warming predicted to occur in the next 20 years will make the earth warmer than it has been in the past 100,000 years. It can be assumed that there will be major practical impacts of such a warming, but little research has been done to define such impacts. Indeed, warming by a few degrees may seem to be a small effect to the man-in-the-street since weather fluctuations are larger than that.

We have estimated how greenhouse warming will alter the number of days in which temperatures exceed a given threshold as a means to illustrate that warming by a few degrees (centigrade) is a large climate change. Although global climate models are not designed for local studies, we can obtain this estimate by compiling climatological data for a given city from a long series of daily observations (including maximum and minimum temperatures for each day) and adding to this record the mean (monthly) increase in daily maximum temperature and in daily minimum temperature as predicted by the climate model for the gridboxes nearest that city. This procedure tends to minimize the effects of any errors in the model's control run climatology. Although the procedure neglects changes in the higher moments of the temperature distribution, examination of our model results indicates that such changes are small.

We first carried out this procedure for the warming predicted by climate models as an equilibrium response to doubled atmospheric CO_2. This is a large climate change, some 4-5°C in the United States, which would be applicable to the middle of next century, if the trace gas growth rate of Scenario A is approximately correct and if the climate sensitivity of current GCMs is approximately correct.

The results of this exercise for doubled CO_2 are shown in Fig. 12 for several cities in the United States. The number of days per year in which the maximum daily temperature exceeds 100°F (38°C) increases from about one to 12 in Washington and from three to 20 in Omaha. The number of days with maximum temperature exceeding 90°F (32°C) increases from about 35 days to 85 days in both cities. The number of days per year in which the nighttime temperature does not fall below 80°F (27°C) increases from less than one day in both cities to about 10 days in Omaha and about 20 days in Washington, D.C. Analogous results for six other U.S. cities are included in Figure 12.

We reiterate here the principal reasons why these estimates may differ from the real world response. First, the estimates are based on a model with a sensitivity of 4°C for doubled CO_2; the real world sensitivity is uncertain within the range from about 2°C to 5°C. Second, the model assumes that the ocean will continue to transport heat essentially as it does today; if North Atlantic deep water formation and the Gulf Stream should be substantially modified, for example, that could change the results for a location such as Washington, D.C. And third, there are many small-scale processes that are not resolved by the model, which could cause local responses to vary.

We make similar estimates for the number of days with temperatures exceeding 90°F for the smaller climate changes which are expected during the next few decades for our extreme trace gas scenarios A and C (Fig. 14). In scenario A, profound changes in the climate would be obvious to the man-in-the-street within the first few decades of the twenty-first century. On the other hand, in scenario C the changes in decadal mean values remain smaller than the year-to-year fluctuations in the number of days with extreme temperatures. This does not imply that the climate change in scenario C is negligible, but scenario C obviously would have much smaller practical impacts than would scenario A.

Conclusion: Although there has been little quantitative research on climate impacts of greenhouse warming, it is apparent that the temperature changes predicted to result from trace gas scenarios A and B would dramatically alter the climate perceived by the man-in-the-street.

6. Climate Response Time: Implications for Emissions Policies

One aspect of the greenhouse climate problem which is particularly relevant to policy considerations is the response time of the climate system. Principally because of the great heat capacity of the oceans, the earth does not immediately respond to a change in climate forcing, but rather tends to adjust slowly over a period of years. Unfortunately, we do not yet have an accurate assessment of what the climate response time is.

The climate response time is in fact a function of climate sensitivity, as described in attachment B (cf. p. 11). If climate sensitivity is only 1.5-2°C for doubled CO_2, the response time may be only of the order of 10 years. But if climate sensitivity is 2.5-5°C, as current GCMs suggest, the response time is in the range from a few decades to a century.

The implication is that a large part of the warming attributable to trace gases man has added to the atmosphere probably has not yet appeared. In addition to the warming which has occurred over the past century, we are committed to additional warming, even if increases of trace gases should be terminated immediately.

Determination of the magnitude of this unrealized warming would be greatly aided by research directed at improving our understanding of climate sensitivity. The single measurable quantity which would be most helpful in this regard is the rate at which heat is being stored in the ocean. Higher climate sensitivities (and hence greater values for the amount of unrealized warming already 'in the bank') have associated with them greater rates of heat storage in the ocean. Accurate monitoring of ocean temperature along a number of ocean transects is required for this purpose. Other key measurement needs are mentioned in the next section.

Conclusion. The finite response time of the climate system implies that there is unrealized greenhouse warming already 'in the bank' or 'in the pipeline'. This yet to be realized warming calls into question a policy of "wait and see" regarding the issue of how to deal with increasing atmospheric carbon dioxide and other trace gases.

7. What is Needed to Improve Understanding of the Greenhouse Effect and Climate Predictive Capabilities?

Scientific evidence confirming the essence of the greenhouse theory is overwhelming. The greenhouse effect is real, it is coming soon, and it will have major effects on all peoples. The greenhouse issue has not received the attention it deserves because the climate trends have not yet risen clearly above the level of natural climate variability. However, based on our model results, greenhouse effects should begin to be apparent within the next decade.

As greenhouse climate change begins to appear, people will ask practical questions and want quantitative answers. We are now totally unprepared to provide information of the specificity that will be required. Vast improvements are needed in our understanding of the climate system and our ability to numerically simulate climate change. Key areas requiring better knowledge include the ocean circulation and heat storage, ice sheet dynamics, ground moisture and vegetation distributions, and climate feedback processes involving cloud properties, sea ice cover, the atmospheric water vapor distribution, and effects of climate change on atmospheric trace gas abundances. These research tasks will require major long-term efforts

The greatest need, in my opinion, is for global observations of the climate system over a period of at least a decade. It is important that observational data systems be in place by the 1990's, as greenhouse effects become significant. Observations are needed to document and quantify climate trends, to allow testing and calibration of global climate models, and to permit analysis of many small-scale climate processes which must be parameterized in the global models. The data needs will require both monitoring from satellites and in situ studies of climate processes. A comprehensive discussion of required observations has been prepared by the Earth System Sciences Committee (appointed by the NASA advisory council) and is presently in press [Earth System Science: A Closer View].

Conclusion: As greenhouse climate effects inevitably grow, so will the needs for quantitative evaluation of observed climate change and reliable prediction of the consequences of alternative trace gas emission scenarios. This will require long-term global observations of the climate system accompanied by a vigorous research program.

Acknowledgement. The graphics for this testimony were produced on short notice by P. Palmer, J. Jonas and J. Mendoza.

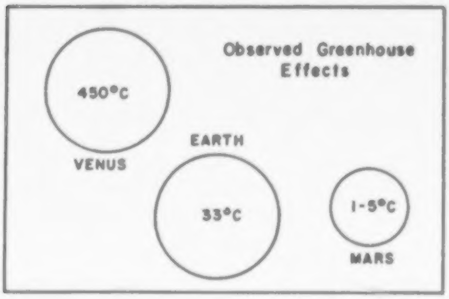
Attachments*

A. Global Trends of Measured Surface Air Temperature, J. Hansen and S. Lebedeff, Journal of Geophysical Research, November, 1987 (in press).

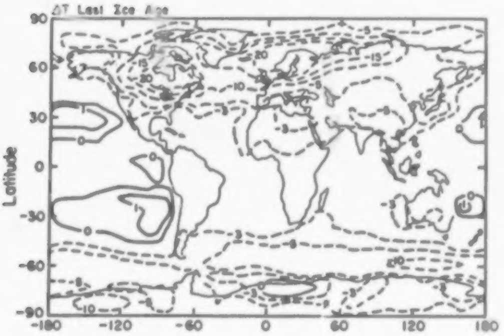
B. Climate Response Times: Dependence on Climate Sensitivity and Ocean Mixing, J. Hansen, G. Russell, A. Lacis, I. Fung, D. Rind and P. Stone, Science, 229, 857-859, 1985.

* Because of its length (28pp.) attachment A is included only with the primary copy of this testimony; copies of it are available from NASA Goddard Institute for Space Studies, 2880 Broadway, New York, NY 10025

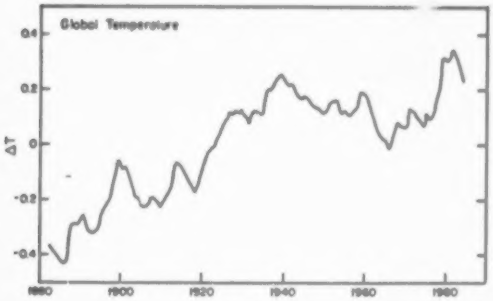
EMPIRICAL BASIS OF UNDERSTANDING


Observed Greenhouse Effects
450°C
VENUS
EARTH
33°C
1-5°C
MARS

OTHER PLANETS:
Venus (400°C), Earth (15°C) and Mars (-50°C) have a broad range of temperatures consistent with greenhouse gas abundances


ΔT Last Ice Age
90
60
30
0
-30
-60
-90
Latitude
-180
-120
-60
0
60
120
180

PALEOCLIMATE RECORDS:
Glacial to interglacial climate changes were accompanied by large changes in atmospheric CO_2, which appear to have been the principal mechanism of climate change



RECENT CLIMATE TRENDS:
Global warming of 0.6°C (1°F) in the past century is consistent with the increase of atmospheric CO_2 and trace gases in that period

Fig. 1. Examples of empirical data which provide quantitiative estimates of climate sensitivity.

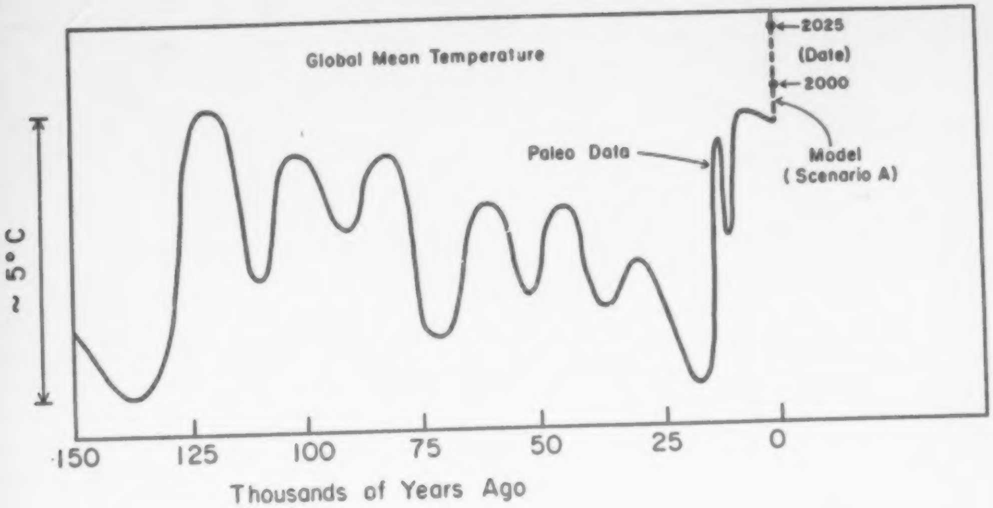


Fig 2. Smoothed global mean temperature trend during the past 150,000 years, and the simulated future temperature trend for trace gas emission scenario A.

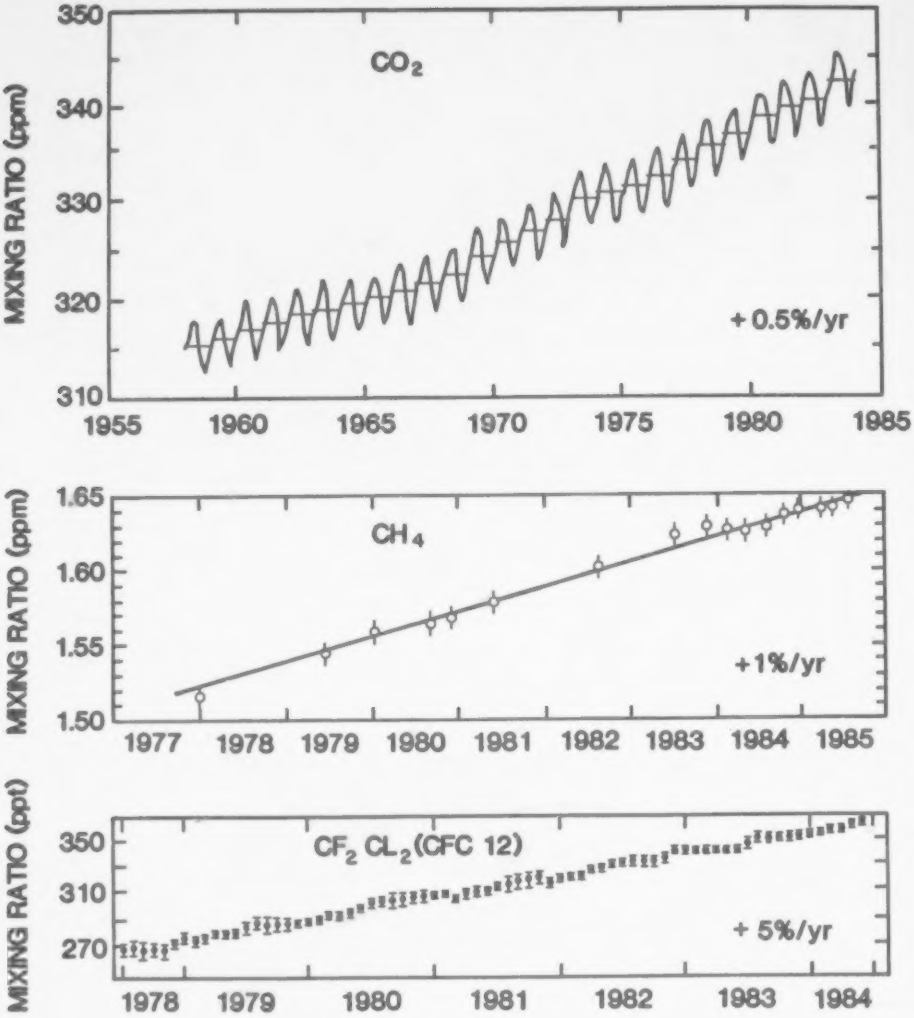


Fig. 3. Recent trends in the atmospheric abundance of three of the principal greenhouse gases in the earth's atmosphere.

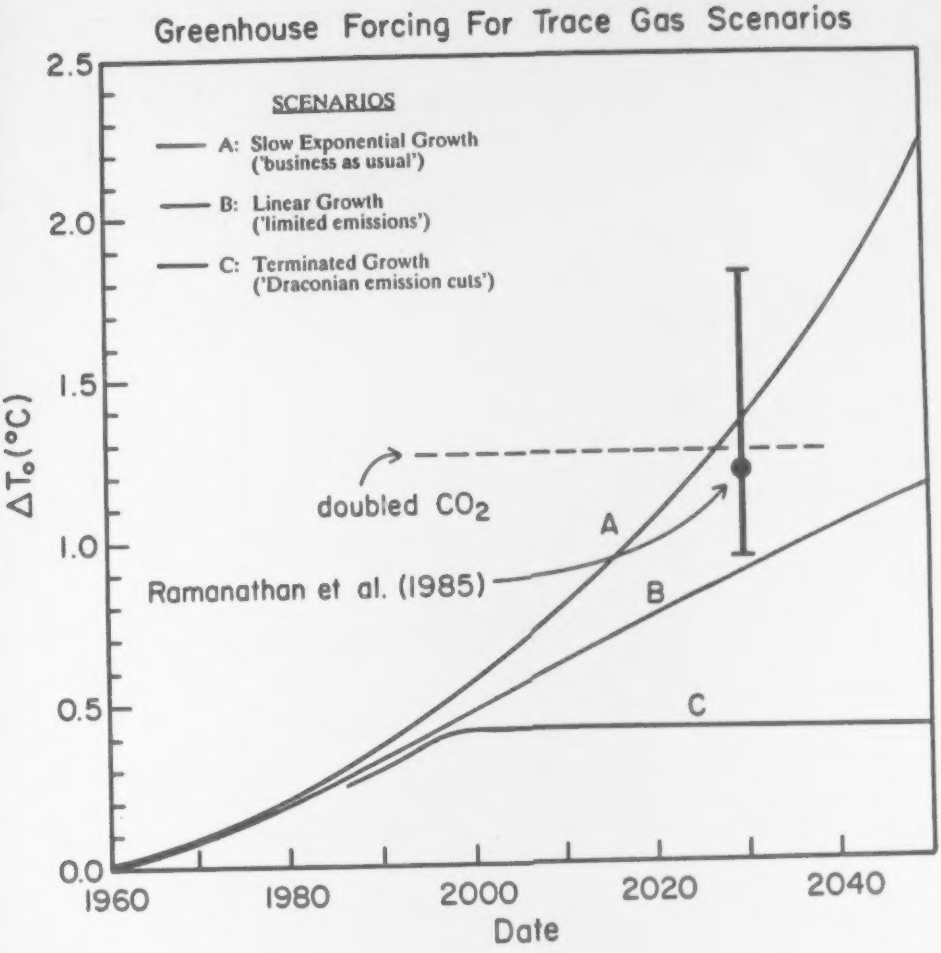


Fig. 4. Three trace gas scenarios used for simulations of future climate with the GISS GCM, as described in the text. ΔT_0 is the "greenhouse forcing", specifically the equilibrium mean global warming that would occur if there were no climate feedbacks. The doubled CO_2 level of forcing, $\Delta T_0 = 1.25°C$, occurs when the CO_2 and trace gases added after 1958 provide a forcing equivalent to doubling CO_2 from 315 ppm to 630 ppm. The CO_2 + trace gas forcing estimated by Ramanathan *et al*. (*J. Geophys. Res*., *90*, 5547-5566, 1985) for 2030 is also illustrated.

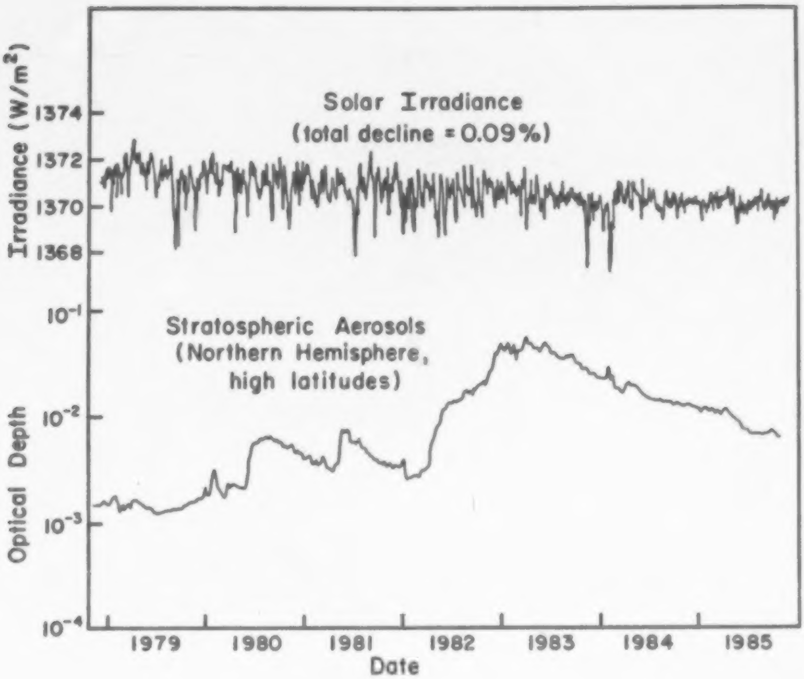
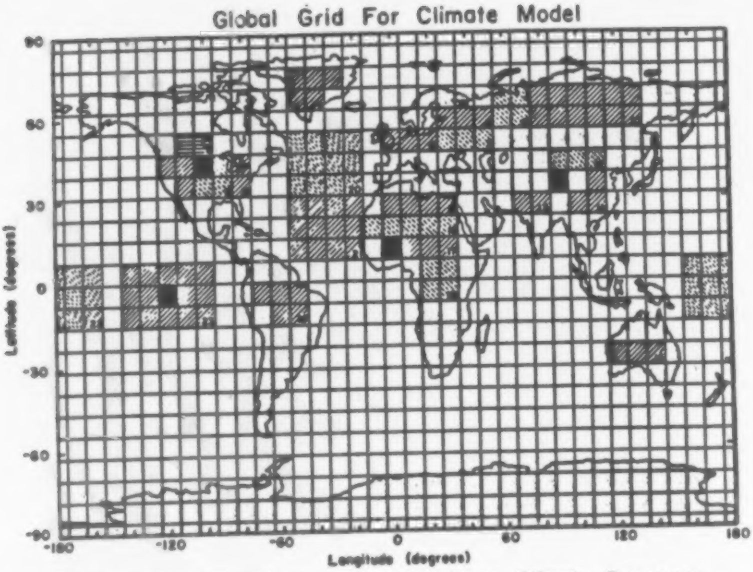


Fig. 5. Solar irradiance and optical depth of stratospheric aerosols, both as observed from the NASA Nimbus 7 satellite.


Global Grid For Climate Model
90
60
30
0
-30
-60
-90
Latitude (degrees)
-180
-120
-60
0
60
120
180
Longitude (degrees)

Fundamental Equations

Conservation of momentum: (Newton's second law of motion)

$$\frac{d\mathbf{V}}{dt} = -2\boldsymbol{\Omega} \times \mathbf{V} - \rho^{-1}\nabla p + \mathbf{g} + \mathbf{F} \qquad \text{(T1)}$$

Conservation of mass: (continuity equation)

$$\frac{d\rho}{dt} = -\rho\nabla \cdot \mathbf{V} + C - D \qquad \text{(T2)}$$

Conservation of energy: (first law of thermodynamics)

$$\frac{dI}{dt} = -p\frac{d\rho^{-1}}{dt} + Q \qquad \text{(T3)}$$

Ideal gas law: (approximate equation of state)

$$p = \rho RT \qquad \text{(T4)}$$

Notation

$\mathbf{V}$	velocity relative to rotating earth
t	time
$\frac{d}{dt}$	total time derivative $\left[= \frac{\partial}{\partial t} + \mathbf{V} \cdot \nabla\right]$
$\boldsymbol{\Omega}$	planet's angular rotation vector
ρ	atmospheric density
$\mathbf{g}$	apparent gravity [=true gravity $- \boldsymbol{\Omega} \times (\boldsymbol{\Omega} \times \mathbf{r})$]
$\mathbf{r}$	position relative to planet's center
$\mathbf{F}$	force per unit mass
C	rate of creation of (gaseous) atmosphere
D	rate of destruction of atmosphere
I	internal energy per unit mass [$=c_vT$]
Q	heating rate per unit mass
R	gas constant
c_v	specific heat at constant volume.

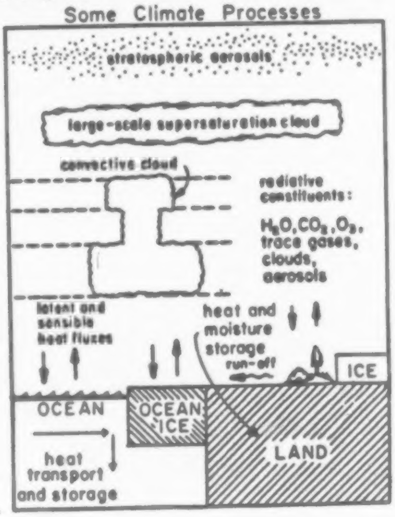

Some Climate Processes
stratospheric aerosols
large-scale supersaturation cloud
convective cloud
radiative constituents:
H_2O, CO_2, O_3, trace gases, clouds, aerosols
latent and sensible heat fluxes
heat and moisture storage
run-off
ICE
OCEAN
OCEAN ICE
LAND
heat transport and storage

Fig. 6. Schematic illustration of GISS global climate model.

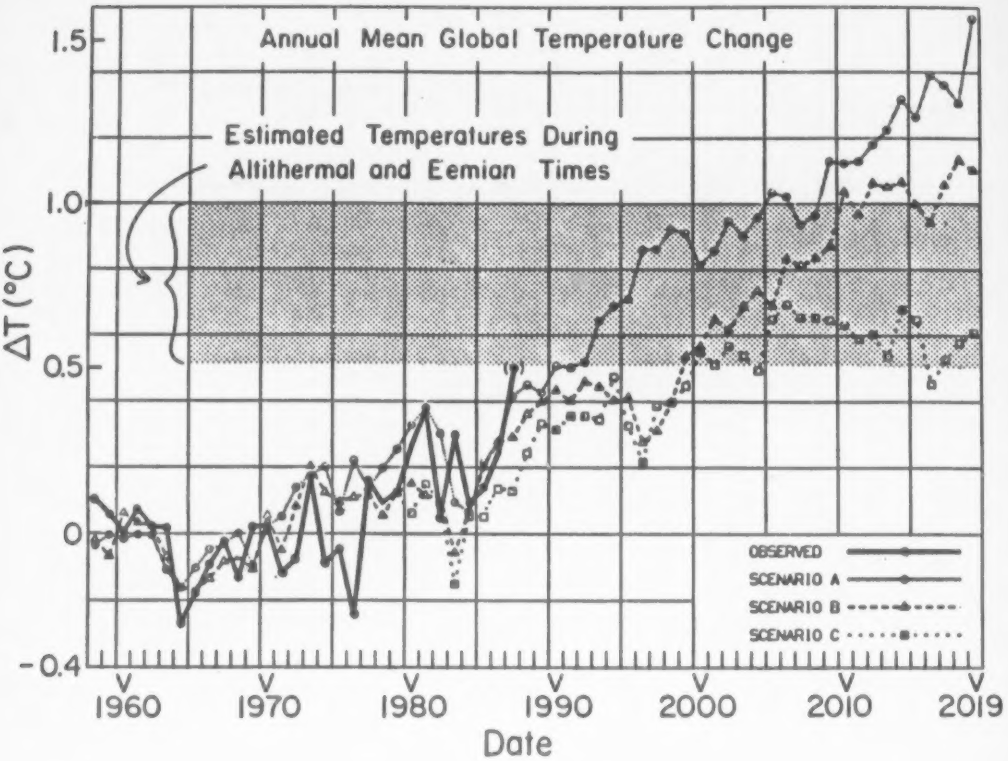


Fig. 7. Annual mean global surface air temperature computed for scenarios A, B and C. Observational data is from Hansen and Lebedeff (*J. Geophys. Res.*, in press). The shaded range is an estimate of global temperature during the peak of the current and previous interglacial periods, about 6,000 and 120,000 years before present, respectively. The zero point for observations is the 1951-1980 mean; the zero point for the model is the control run mean. Observed temperature anomaly for 1987 is based on available station data for January 1 to November 1.

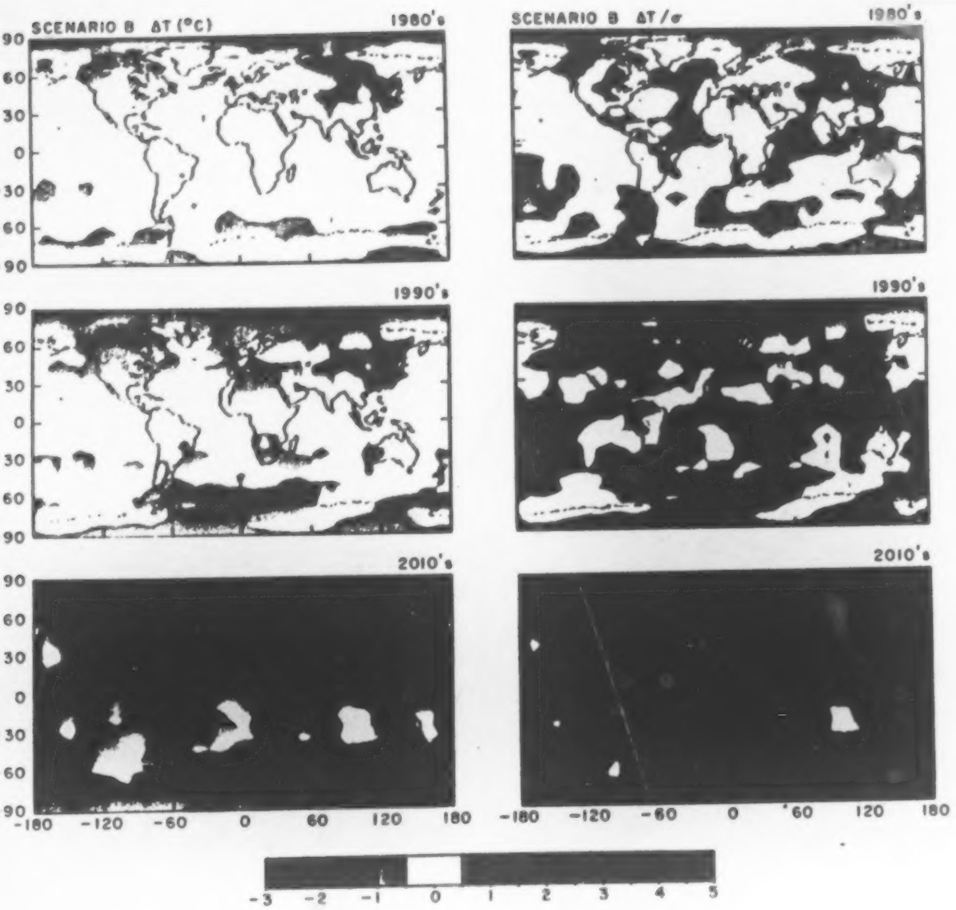

SCENARIO B ΔT (°C)
1980's
SCENARIO B ΔT/σ
1980's
1990's
1990's
2010's
2010's
90
60
30
0
-30
-60
-90
-180
-120
-60
0
60
120
180
-180
-120
-60
0
60
120
180
-3
-2
-1
0
1
2
3
4
5

Fig. 8. Left side: decadal mean temperature change obtained for scenario B, relative to the control run, for the decades 1980's, 1990's and 2010's. Right side: ratio of the computed temperature change to the interannual variability of the annual mean temperature in the 100 year control run.

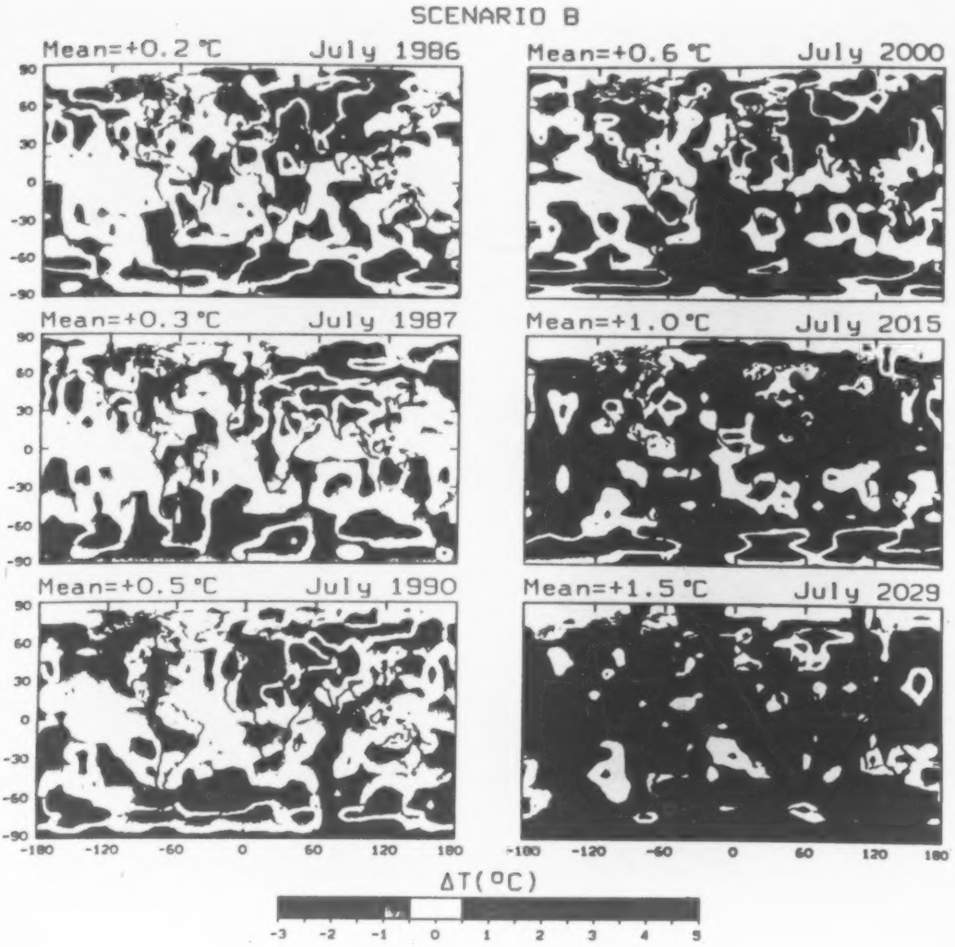

SCENARIO B
Mean=+0.2 °C
July 1986
Mean=+0.6 °C
July 2000
Mean=+0.3 °C
July 1987
Mean=+1.0 °C
July 2015
Mean=+0.5 °C
July 1990
Mean=+1.5 °C
July 2029
90
60
30
0
-30
-60
-90
-180
-120
-60
0
60
120
180
ΔT(°C)
-3
-2
-1
0
1
2
3
4
5

Fig. 9. Simulated July surface air-temperature anomalies for six individual years, compared to 100 year control run with 1958 atmospheric composition.

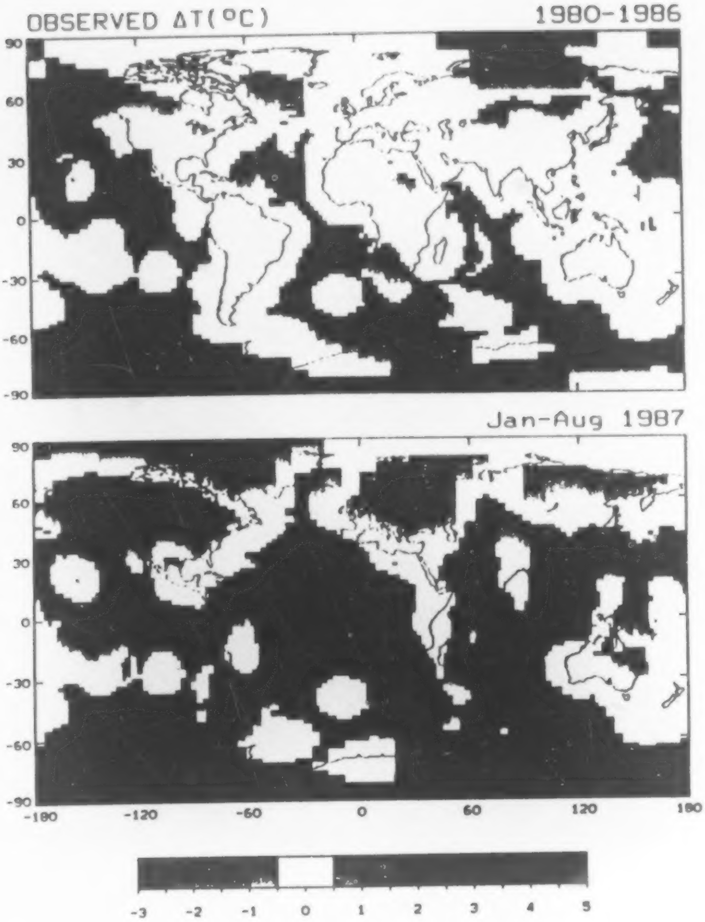

OBSERVED ΔT(°C)
1980-1986
Jan-Aug 1987
90
60
30
0
-30
-60
-90
-180
-120
-60
0
60
120
180
-3
-2
-1
0
1
2
3
4
5

Fig. 10. Observed surface air temperature anomalies in the 1980's, relative to the 1951-1980 climatology of Hansen and Lebedeff (*J. Geophys. Res.*, in press). (a) is the seven-year mean, 1980-1986, and (b) the anomaly for January 1, 1987 to September 1, 1987.

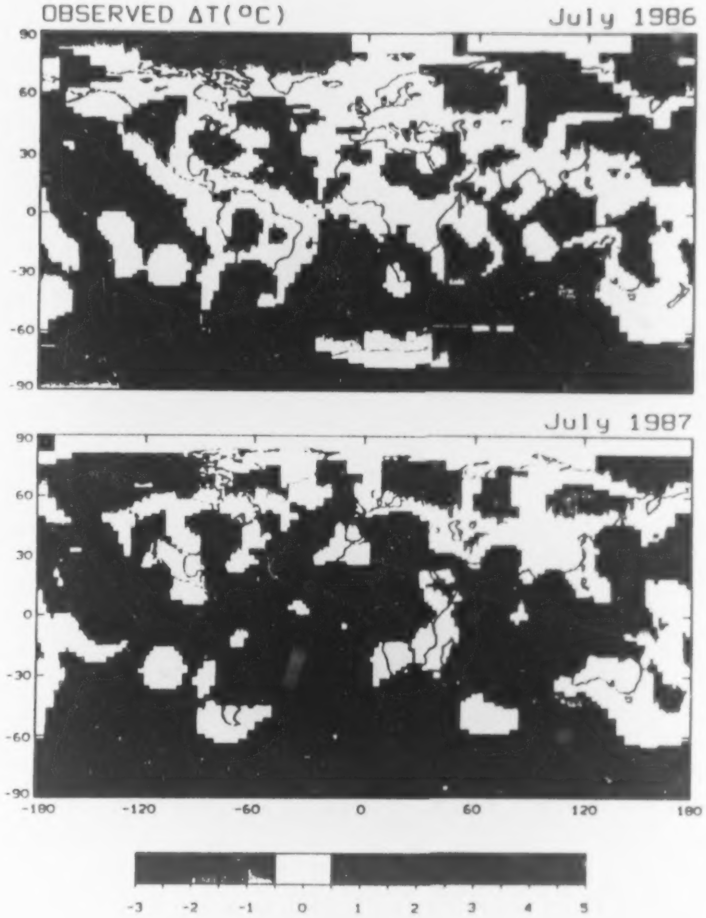

OBSERVED ΔT(°C)
July 1986
July 1987
90
60
30
0
-30
-60
-90
-180
-120
-60
0
60
120
180
-3
-2
-1
0
1
2
3
4
5

Fig. 11. Observed July surface air temperature anomalies in 1986 and 1987, relative to 1951-1980 climatology.

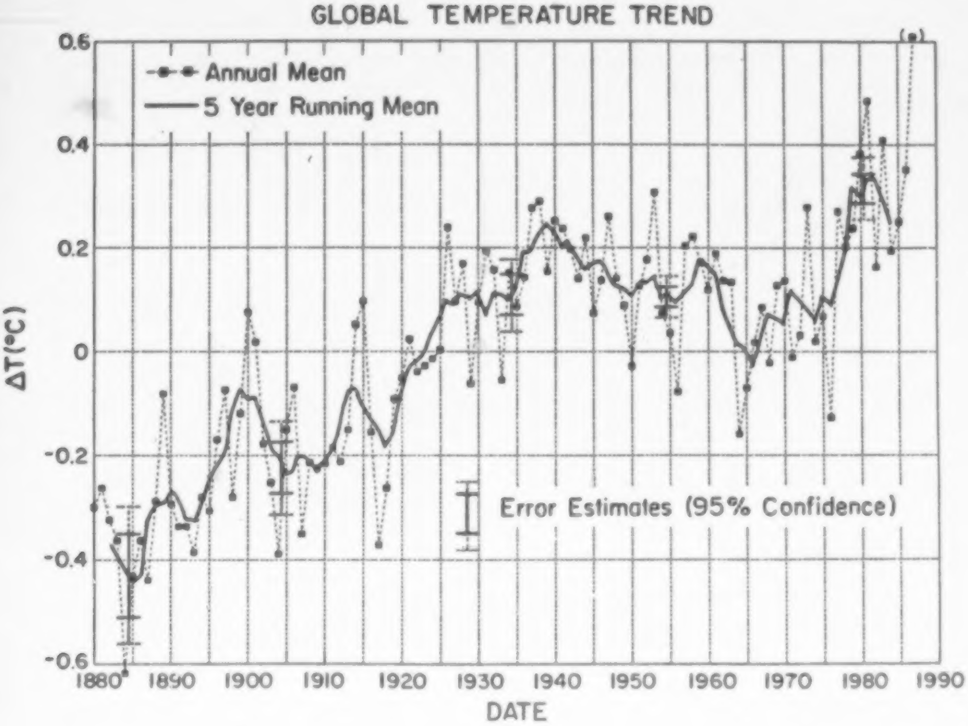


Fig. 12. Global temperature trend for the past century. The 1987 point is an estimate based on the data from January 1 to November 1.

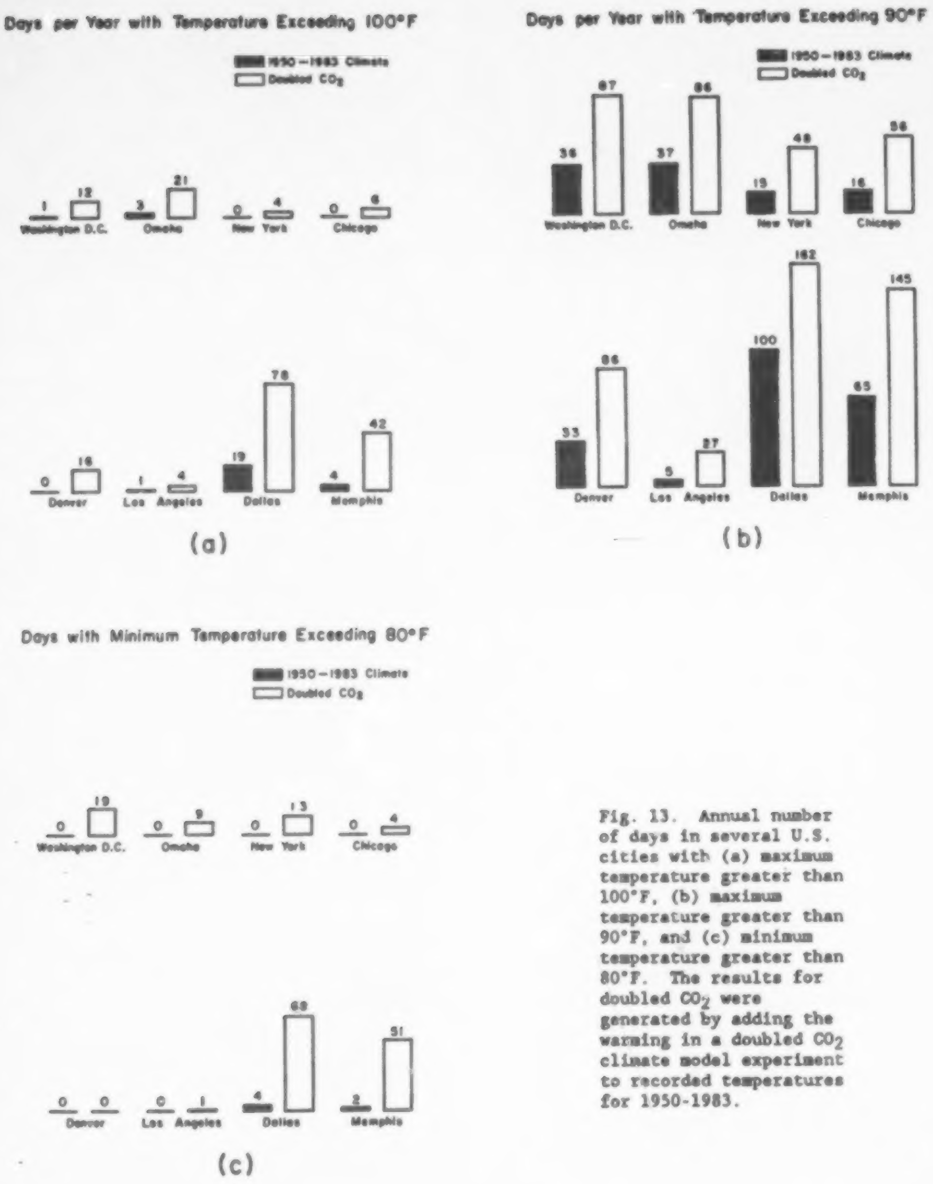


Fig. 13. Annual number of days in several U.S. cities with (a) maximum temperature greater than 100°F, (b) maximum temperature greater than 90°F, and (c) minimum temperature greater than 80°F. The results for doubled CO_2 were generated by adding the warming in a doubled CO_2 climate model experiment to recorded temperatures for 1950-1983.

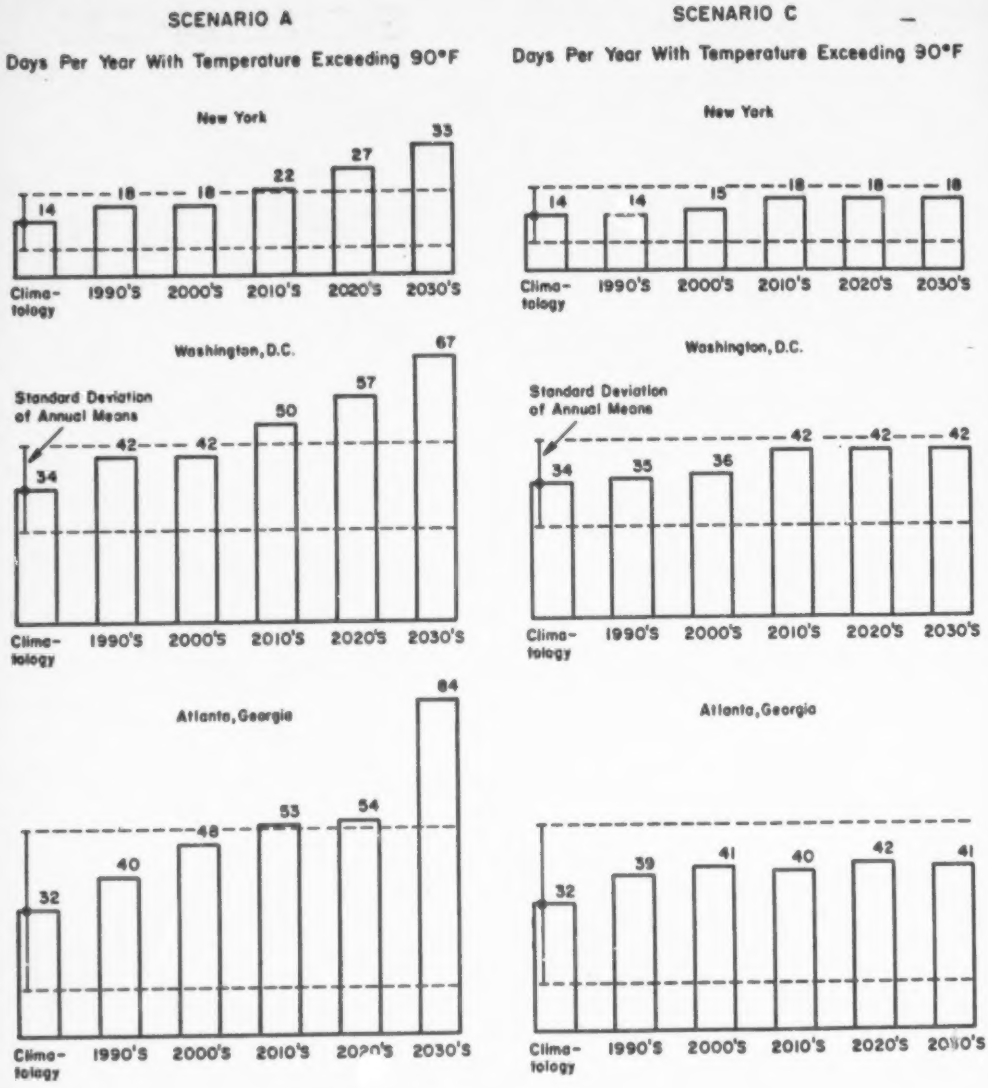


Fig. 14. Annual number of days in three U.S. cities with maximum temperature greater than 90°F. Results are shown by decade for the two extreme trace gas scenarios, A and C.

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SCIENCE

Climate Response Times: Dependence on Climate Sensitivity and Ocean Mixing

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Climate Response Times: Dependence on Climate Sensitivity and Ocean Mixing

Abstract. *The factors that determine climate response times were investigated with simple models and scaling statements. The response times are particularly sensitive to (i) the amount that the climate response is amplified by feedbacks and (ii) the representation of ocean mixing. If equilibrium climate sensitivity is 3°C or greater for a doubling of the carbon dioxide concentration, then most of the expected warming attributable to trace gases added to the atmosphere by man probably has not yet occurred. This yet to be realized warming calls into question a policy of "wait and see" regarding the issue of how to deal with increasing atmospheric carbon dioxide and other trace gases.*

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The abundances of CO_2 and other trace gases in the atmosphere are changing, and it is believed that this change will affect global climate (*1–4*). The global mean surface air warming at equilibrium ($t \rightarrow \infty$) expected to result from a doubling of CO_2 (from, say, 300 to 600 ppm) has been estimated (*1, 2*) as

$$\Delta T_{eq}(2 * CO_2) = 3.0^\circ \pm 1.5^\circ C \qquad (1)$$

with the range being a subjective estimate of the uncertainty based on climate modeling studies and empirical evidence for climate sensitivity.

If there were no climate feedbacks (that is, if the atmospheric temperature gradient and all other factors were fixed), the planet would have to warm by

$$\Delta T_0(2 * CO_2) = 1.2^\circ \text{ to } 1.3^\circ C \qquad (2)$$

to restore the radiation balance with space after CO_2 is doubled (*5, 6*). Thus the climate sensitivity (Eq. 1) implies a net climate feedback factor

$$f = 2.4 \pm 1.2 \qquad (3)$$

where f is the ratio of the equilibrium surface air warming to the warming that would have occurred in the absence of any feedbacks.

An important point in evaluating the transient response to a change in CO_2 is that the response time depends on f. This is illustrated by some simple but progressively more realistic systems. First, consider an atmosphereless blackbody planet ($f = 1$). If the equilibrium temperature of this planet suddenly changes a small amount (say, because of a change in the solar constant), it will approach its new temperature exponentially with the blackbody e-folding time (*3*)

$$\tau_b = c/4\sigma T_i^3 \qquad (4)$$

where c is a time-invariant heat capacity per unit of area, σ the Stefan-Boltzmann constant, and T_i the initial temperature.

Second, consider a planet with climate feedback factor f and fixed heat capacity c. This system has the e-folding time (*6*)

$$\tau = f\tau_b \qquad (5)$$

because most climate feedbacks come into play only in response to the climate change (not the change in climate forcing). For example, if CO_2 is doubled, the initial heating is ~4 W m^{-2}, independent of f or $\Delta T_{eq}(2 * CO_2)$. However, if positive feedbacks come into play, such as the water vapor feedback that responds to temperature, the heating decreases more gradually than in the absence of the positive feedback, and the full response is delayed.

In these examples the heat capacity c is in immediate thermal contact with the atmosphere. This is relevant to a planet totally covered by a mixed-layer ocean, if there is negligible heat exchange between the mixed layer and the deeper ocean. For mixed-layer depth $d_0 = 100$ m and $T_i = 255$ K, the effective temperature of the earth, τ_b is ~3.5 years and thus $f = 3$ yields $\tau = 10$ years.

The earth is more complex than this, principally because there is significant heat exchange between the mixed layer and deeper ocean, as recognized in the CO_2 assessment reports (*1, 2, 4*) and earlier (*7*). Also, we must account for the fact that oceans cover only 70 percent of the earth.

The box diffusion ocean model of Oeschger *et al.* (*8*) provides insight into the effect of the deeper ocean on climate sensitivity. This model has a well-mixed upper layer connected to the deeper ocean by Fickian diffusion. The diffusion coefficient k is specified from observed behavior of transient tracers, such as tritium sprinkled on the ocean surface during atomic testing in the 1960's. The d_0 appropriate for time scales greater than 1 year is the global mean annual maximum, ~100 m (*6*). With this d_0, transient tracers imply an effective global k of 1 to 2 cm^2 sec^{-1} (*6, 8, 9*).

The relation between climate response time, τ, and f can be demonstrated by a scale analysis. Let $d = (k\tau)^{1/2}$ represent depth of penetration of temperature change into the diffusive layer and $D = d_0 + d$ represent total depth of penetration. The surface response time for the box diffusion model is proportional to the depth of penetration of the temperature change. Thus

$$\tau \simeq \frac{D}{d_0}\tau_0 = \frac{D}{d_0} f \tau_b \qquad (6)$$

where τ_0 is the (isolated) mixed-layer response time and τ_b is the blackbody (no feedback) mixed-layer response time. In the limit $k \rightarrow 0$, $D \rightarrow d_0$ and Eq. 6 reduce to the isolated mixed-layer result (Eq. 5). For large k, $d \simeq (k\tau)^{1/2} >> d_0$ and

$$\tau \simeq \frac{(k\tau)^{1/2}}{d_0} f \tau_b \qquad (7)$$

or, solving for τ

$$\tau \simeq kf^2 \left(\frac{\tau_b}{d_0}\right)^2 \propto f^2 \text{ (large } k) \qquad (8)$$

Typical values for k (1 cm^2 sec^{-1}) and τ_0 (10 years) yield $d \simeq 170$ m, large enough to be nearer the diffusive regime than the isolated mixed-layer regime. More quantitative calculations, given below, indicate that for these values τ is nearly proportional to f^2 for the box diffusion model.

Before examining this model more quantitatively, we incorporate the influence of continental regions on the heat flux into the ocean surface. The effect of continental regions on climate response times was investigated previously in numerical modeling studies (*10, 11*). Heating over land areas can, by atmospheric transports, lead to a greater heat flux into the ocean than would occur over the same area of an all-ocean planet. The heat flux (in watts per square meter) into the ocean is proportional to the deviation of the ocean surface temperature from its equilibrium value (*6*):

$$F = \frac{F_0(2 * CO_2)}{\Delta T_{eq}(2 * CO_2)} (\Delta T_{eq} - \Delta T)$$

$$= \frac{F_0(2 * CO_2)}{f \Delta T_0(2 * CO_2)} (f \Delta T_0 - \Delta T) \qquad (9)$$

where ΔT is the ocean surface temperature departure from the 1 * CO_2 equilibrium reference state, ΔT_{eq} is the equilibrium departure for current atmospheric composition, $F_0(2 * CO_2)$ is the flux into the ocean after CO_2 is doubled and stratospheric temperatures equilibrate but before the ocean temperature responds, and ΔT_0 is the equilibrium temperature change with no feedbacks (f = 1)—a measure of the radiative forcing of the climate system for a given change of atmospheric composition, independent of uncertainty in true climate sensitivity.

The proportionality constant in Eq. 9 can be obtained from a 2 * CO_2 experiment in a three-dimensional (3-D) model with realistic geography. Our 3-D model yields $F_0(2 * CO_2) = 4.3$ W m^{-2} (*5*). On the basis of one-dimensional (1-D) calculations, we estimate that the flux into the surface of an all-ocean planet with this radiation scheme would be 3.5 to 4.0 W m^{-2}. Thus, in this model, heating of continental regions increases the flux into the ocean (per unit of ocean area) by 10 to 20 percent.

The radiative forcing ΔT_0 as a function of CO_2 concentration χ (parts per million), computed with the radiation scheme of our 3-D model (*6*), is fitted by

$$\Delta T_0(\chi) = \ln [1 + 1.2\chi + 0.005\chi^2 + 1.4 \times 10^{-6}\chi^3] \qquad (10)$$

to better than 1 percent for χ between 100 and 1000 ppm. The absolute accuracy of Eq. 10 is estimated to be 10 to 15 percent as a result of uncertainties in CO_2 absorption coefficients and numerical approximations in the modeling (*12*).

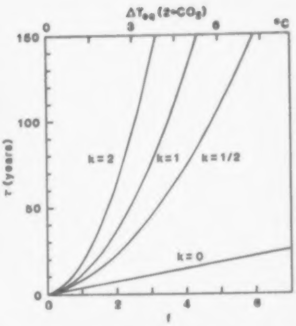

Fig. 1. Ocean surface response time (time to reach 1 − e^{-1} of equilibrium response) for the 1-D box diffusion ocean model as a function of climate feedback factor, *f*, or climate sensitivity to doubled CO_2, $\Delta T_{eq}(2 * CO_2)$ (*k* is the vertical diffusion coefficient in square centimeters per second; the mixed-layer depth d_0 = 100 m). Results depend strongly on *k*, as illustrated, but only slightly on d_0 for the cases in which $k \geq 0.5$ cm^2 sec^{-1}. Calculations are based on Eqs. 9 and 10, with an instant doubling of CO_2 from 300 to 600 ppm.

Equations 9 and 10 and the box diffusion model for ocean heat storage allow a numerical solution for the temperature trend at the ocean surface for any CO_2 scenario. Let us first consider the idealized case of instant doubling of CO_2 from 300 to 600 ppm. The resulting time required for the mixed layer to reach 63 percent of its equilibrium response, τ, is shown in Fig. 1 as a function of *f* or $\Delta T_{eq}(2 * CO_2)$. τ is 15 to 25 years for climate sensitivity 1.5°C but 50 to 100 years for climate sensitivity 3°C, if the diffusion coefficient derived from ocean tracers (k = 1 to 2 cm^2 sec^{-1}) is used.

We next let CO_2 increase linearly from 270 ppm in 1850 to 315 ppm in 1958, and thereafter as observed by Keeling *et al.* (*13*). The results (Fig. 2) show that a large part of the equilibrium CO_2 warming is not yet realized, the unrealized fraction depending strongly on *f* or $\Delta T_{eq}(2 * CO_2)$. If climate sensitivity is 3°C or greater for doubled CO_2, most of the expected equilibrium warming due to the CO_2 increase since 1850 probably has not yet occurred; this must be all the more true for other trace gases, whose greenhouse effect is dominated by chlorofluorocarbons added since 1960 (*14*). This yet to be realized warming calls into question a policy of "wait and see" and "if necessary, make midcourse corrections" regarding the issue of how to deal with increasing atmospheric CO_2 and other trace gases

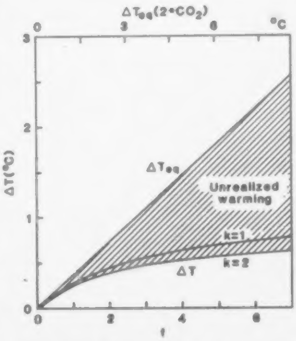

Fig. 2. Ocean surface warming (Δ*T*) and the equilibrium warming (ΔT_{eq}) due to CO_2 added to the atmosphere in the period 1850 to 1980 for the 1-D box diffusion ocean model as a function of *f* or $\Delta T_{eq}(2 * CO_2)$.

The Carbon Dioxide Assessment Committee (*4*) attempted to infer climate sensitivity from the Northern Hemisphere surface air warming of 0.5° to 0.6°C in the period 1850 to 1980 by assuming that the warming was due to the increase in CO_2 during that period. With the added assumption that the temperature trends are similar for the ocean surface and hemispheric surface air, they concluded that this evidence indicates a climate sensitivity in the lower part of the 1.5° to 4.5°C range estimated by Charney (*1*) and Smagorinsky (*2*). However, their analysis assumed τ = 15 years, independent of *f*. As shown above, τ depends strongly, at least linearly, on *f*. If this dependence is included, along with uncertainties in the actual warming, the 1850 CO_2 abundance, and other variable climate forcings, it is difficult to set an upper limit on climate sensitivity by this method. As shown in Fig. 2, a small uncertainty in Δ*T* leads to a large uncertainty in *f* or ΔT_{eq}.

The box diffusion model is a gross simplification of vertical transport in the ocean, and the proportionality of τ to f^2 depends on this diffusive representation as well as on the assumption that a small heat perturbation mixes as a passive tracer. If one used a two-box ocean model with a mixed layer connected to a well-mixed thermocline by a fixed exchange rate, τ would vary linearly with *f*. However, such a two-box model is less realistic than the box diffusion model, failing to represent the increasing penetration of transient tracers with time. Because their observed penetration does increase with time, τ must increase more strongly than linearly with *f* for the real ocean. A more precise conclusion depends on obtaining better data on the world ocean circulation, especially the vertical mixing processes.

The assumption that a heat perturbation mixes as a passive tracer may break down as the climatic warming increases. In the ocean model of Bryan *et al.* (*15*), a warm anomaly of 0.5°C penetrates significantly (~25 percent) less than a similar cold anomaly. Furthermore, global warming will be accompanied by changes in evaporation, precipitation, and wind stress over the ocean surface, and possibly by the addition of fresh water from melting ice sheets—all of which may affect the rate of ocean mixing. There is evidence that some mechanisms of ocean overturning are capable of sudden changes (*16*), and the paleoclimate record reveals cases of large warming within periods of no more than several decades (*16*, *17*). Thus we cannot exclude the possibility that the climate may at some point undergo a rapid transition to the equilibrium climate for current atmospheric composition.

The existence of unrealized warming complicates the CO_2 and trace gas issue and limits the near-term effectiveness of reductions in greenhouse gas emissions. The strong dependence of this unrealized warming on the equilibrium climate sensitivity emphasizes the importance of narrowing uncertainties about the strength of climate feedback processes. This will require better understanding of many components of the climate system including clouds, the cryosphere, biogeochemical cycles, ocean mixing, vegetation, and the land surface.

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12. Our 3-D model [*J. Atmos. Sci.* 111, 609 (1983)] averages gaseous absorption over broad ranges for computational efficiency. This radiation scheme yields a forcing $\Delta T_0 = 1.2°C$ for doubled CO_2 (300 to 600 ppm) and an initial flux $F_0 = 4.3$ W m^{-2} into the ocean in the 3-D model. A more detailed radiation scheme with fine spectral resolution yields $\Delta T_0 = 1.26°C$ for 1-D calculations with a global mean atmospheric profile and would be expected to increase F_0 proportionately, without affecting τ. The latter radiation scheme has been compared with a wide range of other models, including line-by-line calculations, with results agreeing within ~10 percent [F. M. Luther and Y. Fouquart, *WMO Rep. WCP-93* (1984)]. Other published values for ΔT_0 are 1.33°C (*4*) and 1.3°C [V. Ramanathan, *J. Atmos. Sci.* 38, 918 (1981)].
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17 April 1985; accepted 1 July 1985

Senator WIRTH. Dr. Hansen, thank you very much.

Dr. Manabe.

STATEMENT OF DR. SYUKURO MANABE, GEOPHYSICAL FLUID DYNAMICS LABORATORY, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, DEPARTMENT OF COMMERCE

Dr. MANABE. Mr. Chairman and members of the committee, I appreciate the opportunity to appear before you to discuss the issue of global climate change.

Since the previous speakers covered the issue of global warming, I would like to concentrate more on the issue of hydrologic change, which may have important agricultural and water resources implications. These hydrological changes, which are obtained from mathematical models at the Geophysical Fluid Dynamics Laboratory, are examples.

The mathematical model of climate which we use at the Laboratory is somewhat similar to Dr. Jim Hansen's model and many other models. It consists of a three-dimensional model of the atmosphere coupled with models of the land surface process and a simple model of mixed layer oceans.

It contains the process of solar radiative heating and it also contains the process of long range terrestrial radiation cooling from the atmosphere into space. In addition, it includes the hydrologic cycle which we follow with our forecasting model, with which you are familiar with daily forecasts. We follow the evolution of the atmospheric flow based upon hydrodynamical equations of motion by using super computers.

The effect of future greenhouse gases increase was evaluated by comparing two equilibrium climates with high CO_2 concentration and normal CO_2 concentrations. The pictures, please.

[Viewgraph.]

The upper panel of the picture shows the percentage change of soil moisture which we obtained from our model in response to doubling of atmospheric carbon dioxide. The region where it is yellow and orange indicates the area where soil moisture decreased in response to the doubling of greenhouse gases.

The places where they are orange indicate the reduction of soil moisture was 20 percent. And the major fraction of that orange area indicates the increase of soil moisture which is more than 30 percent.

This result indicates that soil moisture is reduced over very extensive regions in the North American Continent in middle and high latitudes. Over Siberia and Canada, these reduction are related to the change in the snow melt processes. What happens is, as you know, in spring the snow melt season comes. The soil is very wet because of snow melt. As the highly reflective snow disappears and intense summer sun starts heating the ground, the soil starts drying very rapidly from spring to summer season.

In the warm CO_2 rich climate, this snow melting season comes earlier so that the spring to summer drying begins earlier, and therefore, summer soil gets drier over a longer period of time. This is one of the important mechanisms which prevails in Canada, Siberia and sometimes the northern part of the United States.

There is another important mechanism which gives you mid-continental summer dryness, which is related to change in precipitation. That will be illustrated in the next picture. This picture looks a little bit like the United States, but I hope you do not take it too seriously. I will explain know what I mean later by that.

On the left-hand side what happened is, in middle latitude a lot of cyclones pass as you know very well. Because of the passage of the cyclone, the precipitation in the mid-latitudes is more than normal precipitation; we call this the middle latitude rainbelt. Now these middle latitude rainbelts tend to be at a little bit lower latitude in winter and they move to a higher latitude in summer season. Come back to winter, and then that rainbelt moves southward again.

Now, in the warm, CO_2-rich climate, moisture-rich air penetrates into higher latitudes making the northern half of the rainbelt wetter and the southern half of the rainbelt dryer.

Since the rainbelt moves from south to north in the middle latitude region, the mid-continental region comes right under the dryer half the part of rainbelt, becoming dryer in response to increase of greenhouse gases. Therefore the mid-continental region becomes drier in response to increase of greenhouse gases. When you put these things together, then you get fast changes in the snow melt season. Another factor is the change in the rainfall distribution. Combine them together, and you get enhanced dryness over very extensive region in the mid-continental region of the northern hemisphere.

When you look at the area picture which shows that very extensive and constant dryness, you have to keep in mind that this result is meaningful only in a very broad-scale context. At the present time this mathematical model, even though we use a large computer, the computer is not fast enough, so that computational resolution of these models is very crude.

For example, if I can look again at the picture which I showed earlier—can I see the picture again. A change in the southern hemisphere or tropics is not very significant, which is indicated by the lower picture. That red area is more trustworthy than the orange area in the lower pictures.

You cannot trust the southern hemisphere. You cannot trust the model's results in the east coast of the United States because the results are dominated by some of our tropical cyclones, and our model does not do very well in reproducing these features.

Furthermore, hydrological variations have a large natural, year-to-year fluctuation. Therefore, some of small scale features are obscured by these natural fluctuations.

So what happened? Another implication of this large natural fluctuation of hydrology is that it will probably take longer to detect convincingly the signal in the mid-continental summer dryness than the temperature warming, which at present we feel that we have seen about 0.5 degree centigrade warming during this century. It is consistent with our model prediction but we cannot prove that these warming are, indeed, due to greenhouse warming yet. Categorically, we cannot prove that. It may take even longer to detect these hydrological changes.

Also you have to realize that among the research group we have not reached unanimous agreement on the result of mid-continental dryness. However, more recent results are very similar to to the results which I presented here today. I feel that the large scale mid-continental dryness is accompanied by global warming and it is a rather a robust phenomenon.

The kind of summer drying which I am showing here would be realized in the magnitude that I have shown in the latter half of the next century when the doubling effect of warming is expected to be realized.

From the above discussion, it is essential that increased research effort be devoted to the improvement of the climate models to increase our confidence in the prediction of climate models about future greenhouse-induced warming.

In addition, the results presented here could provide an added incentive for improved water management. What happens is that summer becomes dryer but because the rainbelt moves north, the northern half increases so winter becomes wetter. This suggests some interesting water management strategies which we can employ in the future.

By the same reasoning, research for the development of agricultural species which can survive under significantly different environmental conditions is encouraged.

In summary, the climate gets warmer and the mid-continental region over U.S.A. becomes dryer as CO_2 concentration in the air increases. These very interesting changes, the effect of these changes on the agricultural and cultural practices is very interesting to study.

The progress in both of these areas would better prepare us for natural fluctuations of climate as well as climate change due to greenhouse gases.

Mr. Chairman, this completes my prepared statement.

[The prepared statement of Dr. Manabe follows:]

STATEMENT OF

SYUKURO MANABE
GEOPHYSICAL FLUID DYNAMICS LABORATORY
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

BEFORE THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES
UNITED STATES SENATE

NOVEMBER 9, 1987

Mr. Chairman and Members of the Committee, I appreciate the opportunity to appear before you today to comment on the subject of future changes in climate due to the increase of greenhouse gases. Since previous speakers have discussed the climatic warming due to increased greenhouse gases, I would like to focus my presentation on the large-scale changes in soil wetness. These changes, which may have profound agricultural and other implications, have received increased emphasis in research activities at various institutions in North America and Europe. I will discuss this issue based upon the results (1,2) from the mathematical models of climate developed at the Geophysical Fluid Dynamics Laboratory of NOAA.

The mathematical model of climate used for this study is a three-dimensional model of the atmosphere coupled with models of the land surface and a simple mixed layer ocean. The atmospheric part of this climate model is very similar to the numerical weather prediction models which have been used successfully by the National Weather Service of the United States and many other countries for daily weather forecasting. The model takes into consideration the effects of solar and terrestrial radiation and the hydrologic cycle and explicitly follows the general circulation in the atmosphere by the hydrodynamical equations. It has been shown that this type of climate model successfully simulates the seasonal and geographical distribution of climate. The impact of increased greenhouse gases on climate was evaluated by comparing the two climates of the model with normal and above-normal concentrations of atmospheric carbon dioxide.

A map of the CO_2-induced percentage-change of soil moisture for the June-July-August period is illustrated in Fig. 1. This figure indicates that, in summer, soil becomes drier over very extensive, mid-continental regions of North America, Southern Europe and Siberia in response to the doubling of atmospheric carbon dioxide. In some regions, the reduction amounts to a substantial fraction of the soil moisture present in the standard-CO_2 case.

Over Siberia and Canada, CO_2-induced changes in snowmelt are responsible for the reduction in soil moisture. In these regions extensive snow cover prevails during winter before melting in the late spring. Since snow cover reflects a large fraction of incoming sunshine, its disappearance increases the absorption of solar energy by the land surface to be used as the latent heat for evaporation. Thus, the end of the spring snowmelt season marks the beginning of the seasonal drying of the soil that takes place in summer. In the warmer high-CO_2 world the snowmelt season comes earlier, bringing an earlier start of the spring to summer reduction of soil moisture. As a result, the soil becomes drier in summer.

Over the Great Plains of North America the earlier snowmelt season also contributes to the CO_2-induced reduction of soil wetness in summer. Changes in the mid-latitude precipitation pattern also contribute to the reduction of soil wetness in summer over North America and Southern Europe. Both of these regions are under the influence of a rainbelt associated with the typical path taken by mid-latitude low pressure systems. In the high CO_2 atmosphere, warm moisture-rich air penetrates further north than in the normal-CO_2 atmosphere. Thus, the precipitation rate increases significantly in the northern half of the mid-latitude rainbelt, whereas it decreases in the southern half. Since the rainbelt moves northward from winter to summer a mid-latitude location is in the northern half of the rainbelt in winter and in its southern half in summer. At such a location the CO_2-induced change in precipitation rate becomes negative in early summer, contributing to a reduction of soil moisture. The summer dryness is enhanced further due to the increased sunshine reaching the ground as reduced evaporation from the drier continental surface causes a decrease in cloudiness.

The summer reduction of soil wetness discussed above does not continue through winter. In response to the increase of atmospheric carbon dioxide, soil wetness increases over extensive mid-continental regions of middle and high latitudes in winter. In middle latitudes, this is mainly due to the increase of precipitation in the northern half of the middle latitude rainbelt. In high latitudes, a larger fraction of precipitation is realized as rainfall, making soil wetter.

Upon inspecting Fig. 1, one should keep in mind that only these very broad-scale features of the soil moisture changes are significant. For example, many of the small-scale features in the tropics and Southern Hemisphere are not regarded with much confidence. This is partly because the climate models used in this study have coarse computational resolution and fail to simulate the small-scale features of the hydrologic change. Furthermore, the detailed features of the CO_2-induced change are often obscured by the natural fluctuation of soil wetness, thereby making the identification of these features very difficult. This large natural hydrologic variability also implies that it will take much longer to detect the mid-continental enhancement of summer dryness than the global warming of the atmosphere.

One should also note that research groups have not reached unanimous agreement (3,4) on the issue of the mid-continental summer dryness, though the results from recent studies (5,6) appear to agree with those presented here. In my opinion, some uncertainty in the estimate of the future hydrologic change stems from the difficulty of reliably incorporating into a climate model various relevant physical processes, such as the land surface water budget and ocean-atmosphere interaction. Nevertheless, the above discussion clearly indicates that the reduction of the mid-continental soil moisture in summer results from global warming of climate and is a rather robust and large-scale phenomenon. In conclusion, I believe it is likely that mid-continental summer dryness will intensify in the Northern Hemisphere accompanied by the increasing greenhouse warming of climate.

From the above discussion, it is essential that increased research effort be devoted to the improvement of climate models to increase our confidence in their projection of CO_2-induced climate change. In addition, the results presented here could provide an added incentive for improved water management. By the same reasoning research for the development of agricultural species which can survive under significantly different environmental conditions is encouraged. Progress in both of these areas would better prepare us for the natural fluctuations of climate as well as climate change due to greenhouse gases.

Mr. Chairman, this completes my prepared statement. I would be glad to answer any questions you might have.

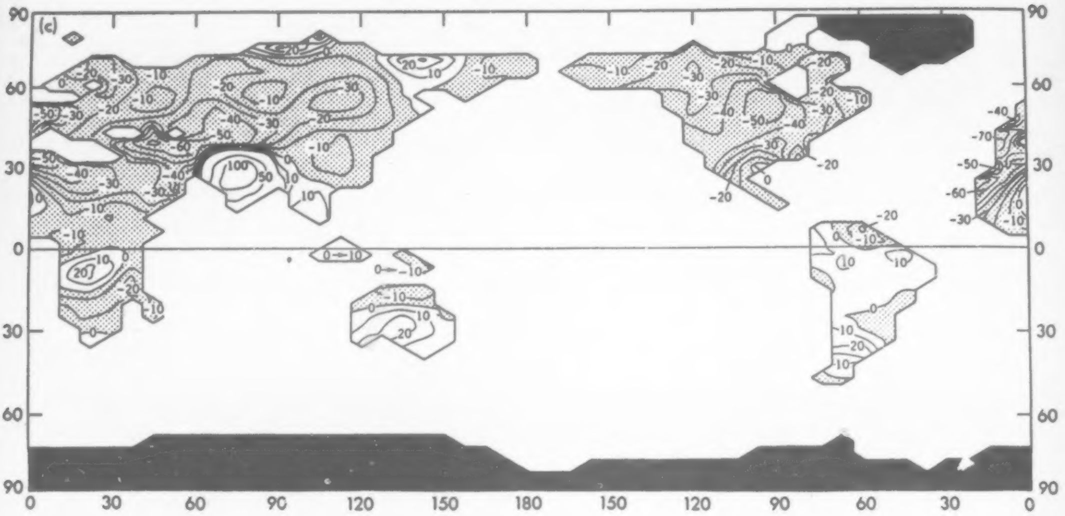
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Fig. 1. The geographical distribution of the percentage change of soil moisture in response to a doubling of CO_2 content for the June-July-August period. The results are obtained from a general circulation model of climate developed at the Geophysical Fluid Dynamics Laboratory of NOAA.

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Senator **Wirth**. Dr. Manabe, thank you very much.

Dr. Leatherman, we thank you very much for manning the projectors. We will have you reimbursed at the appropriate salaries of members of the staff, which is all too low. [Laughter.]

STATEMENT OF DR. STEPHEN P. LEATHERMAN, DIRECTOR, LABORATORY FOR COASTAL RESEARCH, UNIVERSITY OF MARYLAND, COLLEGE PARK, MD

Dr. **Manabe**. I would like to start with some slides, if I may.

[Slides.]

I was asked to address the Committee in terms of the impacts of greenhouse warming on coastal environments in low-lying areas. I think probably the two most important impacts that we are going to see are going to be on terms of the effects on salt marshes, and also, on sandy shorelines. So, I would like to briefly show you a few slides to illustrate these impacts.

As you are probably aware, historically there has been quite a bit of loss of marshes in the United States. Most of this was due to urbanization and has been changed by laws and the U.S. Congress, so that we are not losing that many marshes anymore by direct impacts of filling, dredging and filling operations in urbanization. About 50 percent of our marshes lost have been lost in the northeast part of the United States, and still of course, marsh losses are occurring in Louisiana due to dredging and and other activities.

The impact of accelerated sea level rise will first be noticed or most obvious as marsh erosion. Here we see an area in North Carolina, where you can see the bits of the marsh in the bay, which used to only a few years ago, extend into the bay about 10 meters further. This is the most obvious effect, the actual erosion back of the shorelines. This is happening at a very rapid rate in Louisiana.

However, if we were to really look at how marshes are being lost and as you come closer to home here at the Chesapeake Bay Region over in the Eastern Shore area around Cambridge, there is a brackish water wildlife refuge. I cannot really show it to you, but it is in Cambridge, Maryland, on the Eastern Shore of Chesapeake Bay.

In brief, this is what we can show with the air photographs going back to 1983. You can see the marsh. The marsh is in the white here, and you can see the tidal channel in black. By 1957, notice that the black area, that water, has increased dramatically. In 1964, this air photograph has a lot of reflection off of it, and it is irreversible now. Now, the water is in white. Notice that the water is getting larger in extent.

By 1972, it is actually difficult to see the tidal creek through the marsh. The marsh has disintegrated. This area has lost about 5,000 acres of marsh since 1938. This, by the way, is one of the most important parts of the National Wildlife Refuge System.

This is one of the few areas to see marsh loss, in addition of course, to Louisiana which is losing about 40 square miles of marsh per year. It was interesting to find these results. This is what the area looks like on the ground with the color infrared photograph. You can see the channel there and a lot of these open water areas which are, of course, valuable habitat with the loss of salt marshes, are often being more valuable in this area.

One of the things that is going to happen in the future with accelerated sea level rise is that the marsh is going to have to migrate up the land surface, up to the uplands. Here, we can see the situation where marshes have really formed in their present extent over the last 5,000 years when the sea level was really rising very slowly.

If we raise the sea level rise, then you can see that the marshes are going to largely drown and be pinched out. What is probably more troublesome in some areas, is that there has been urbanization. This is happening rapidly along the Chesapeake Bay. If you go to New Jersey, New York, Long Island, you find that many of the major communities are built along the bay shore, and already bulkheads have been built to protect them from saltwater flooding.

Essentially what we see is, the marshes are going to be squeezed out of existence in the future. There is really no place for them to go.

In an area around Galveston Bay, this is one of the few areas where buildings have been abandoned. You can look at the background and see Galveston, and you see salt marshes growing into the front yard. The guy's shrubbery is dying, obviously. This is an artificial situation where the ground has dropped several feet, about five feet, due to the withdrawal of oil around Galveston Bay.

This is a development of about 2,000 homes which were abandoned and bought up by the Federal Government because they were below sea level. This might pretend something for the future, but I might say that the most likely scenario is trying to keep the bay sailing waters out rather than letting them come through peoples yards.

In Louisiana, since there is not much interest in this area and it is probably the most dramatic example, this is a map showing the present shoreline and what this shoreline will look like in 50 years with just the present trend.

If you add sea level rise to that and accelerate the sea level rise, you can see the dramatic losses where entire parishes or counties will be lost in the future. Louisiana has a tremendous problem, as you know, because of natural compaction and subsidence. The relative rate of sea level rise here is about 10 times that of the national average.

We can look at Louisiana as sort of an example of what is going to happen in the future if the rise rates of a centimeter or about one-half an inch per year are realized, then what we are seeing in Louisiana may be representative of what we are seeing in other parts of the country.

Let me quickly say a few things about sandy beaches and shorelines, because that is the other area in which there are going to be major response to sea level rise, largely a major retreat of our shores.

Here, at Ocean City, MD, we see that there are high rise buildings built along an eroding shoreline. We have historically mapped this area; we have very accurate historical maps and air photographs which we can use by computer analysis to determine the rate of erosion.

This area has eroded about 260 feet in the last 120 years. During that time, the relative rate of sea level rise has been about one foot. So, one foot of rise, 260 feet of erosion. Imagine, the beaches must have been much wider in prior times.

Of course, we mention the sea level rise. The sea levels are already rising. Our earliest records go back to about the 1880's or so and show an upper trend around the United States, except for a few areas like Alaska, where the land is rebounding from other effects. There is has been about a one foot rise along the mid-atlantic coast.

In response to that, we see here a map showing the 1850 shoreline of Ocean City. The ocean is to the right and you see a dash line, that is the 1850 shoreline. The solid line with ticks on it is the 1980 shoreline. Those little ticks are jetties, actually called groins. Then we see the rest of the bay shore which has been urbanized and the bay itself.

What we are seeing here is that 260 feet of erosion. You are looking at the entire width of the island. About 20 percent of the island has eroded away in the last 130 years at Ocean City, MD. This is the result of sea level rise of about one foot.

Here we see the situation today, where there is only about 50 feet of beach in front of these high rise buildings. This is a situation, as I will mention a few minutes later, that is represented up and down the coastline. It is not just indicative of the Ocean City area.

Again, depending upon which climate model is used or which projections are utilized, sea level rise is going to accelerate the low level or the baseline and some of the other higher levels are probably also realistic. We are not sure; it is a fairly wide range. Therefore, the amount of erosion that can be expected is fairly large too.

Here we have done some estimates. We have various methods, algorithms to calculate this. As you can see, the current trend with no accelerated sea level rise, the mid-range low sea level rise, the mid-range high, are evaluated at certain years. This is the amount of beach erosion that ranges from 39 feet by the year 2000 up to 89 feet for the high range by the year 2000. Well, you can see that with these higher rates, clearly the buildings will be in the water quite soon.

In fact, we are expecting more of this sort of situation in the future. We are seeing the beaches continue to shrink, continue to narrow down, and of course, putting these buildings in a much more vulnerable situation during storm conditions.

In fact, if we look at these various scenarios around 44th street of Ocean City, line number two is the present situation; line number three which cuts through some of the high rise buildings by the year 2000 with their present trend accelerated sea level rise; line four shows accelerated sea level rise by the year 2000, showing that the buildings will be out on the beach itself or in the water.

Something like this would be the high rise buildings assuming, of course, the pilings are standing and the building can withstand the storms.

There is some feeling that perhaps the barriers are breaking up. Here is a small barrier island which is disintegrating. In fact, we are seeing quite a bit of this in the Louisiana area, where some large stretches of the barrier grounds are predicted to be destroyed or disappear in the next 50 years.

I just thought I would take a few minutes to march us around the coast line, just to show you that this is not a unique system. Here we are in Massachusetts, south shore, south of Boston. You see a lot of houses on cliffs here, which are just right on the edge. This brings to mind the Federal Emergency Management Administration (FEMA) flood insurance policy.

These areas need to be moved back. At present, people can only be compensated when their houses fall in the water. Move farther south on Fire Island, New York, on the south shore of Long Island, you see a lot of old houses which were built back in the turn of the century. Now they have been drawn to the shoreline with the beaches ever eroding here, about 2 feet per year, which turns out to be the Atlantic Coast average, about 2 or 3 feet per year.

What is perhaps more disturbing, is the fact that more modern houses have been built. Here we are looking at a house that is valued modestly at $2 to $3 million, which has been built along an eroding shoreline, a known eroding shoreline. There are many such properties here in South Hampton, Long Island, New York.

I should point out this particular area, you can see the bay behind. You can see how narrow the barrier is, less than about 800 feet. We are looking at the beach now. Looking back in the winter at the bayside which has ice on it.

In 1938 this is what that same area looked like. It was completely obliterated by the 1938 hurricane. See the telephone lines? It was completely urbanized. All those houses were washed away. The dunes were rebuilt, the houses came back in, and so the area is actually more vulnerable today than what it was in 1938 because sea level has come up about one-half foot since that time in this area.

Again, farther south we are seeing a lot of buildings sitting on the edge of the water, just sort of waiting their turn for the next storm, if you wish. Here in Louisiana, I think you get the idea that something is missing there.

I should also point out that this is continuing. Here's a barrier along the Atlantic Coast of Florida. You can see again, just how narrow these things are, these low-lying land forms. The Atlantic Ocean and the Bay behind. This is another high rise building placed right along the edge of the shoreline.

Again, we found from our work to date that about 90 percent of our sandy beaches are presently eroding along the Atlantic and Gulf Coast, 90 percent. So, it is not an isolated situation. It is a general trend, which we think the only thing that can possibly drive this is sea level rise. Of course, it is going to drive it at a much faster pace in the future.

You might ask, what are we going to do about this? There are really only three general responses. The first is to retreat from the shore, and this is an option of course, for undeveloped areas such as this where there are no facilities, perhaps no oil facilities such as Louisiana to protect it. This is only an alternative.

The second alternative is some of the plans the Corps of Engineers have for stabilizing the shorelines using jetties, groins, sea walls, bulkheads and the like. These, of course, become very expensive and once they are set in place have to be maintained for long periods of time.

This, of course, is an option which has been exercised at Galveston Island. Here is the Galveston sea wall, which was built in 1900 and is still in place doing its job. Of course, the beach has been sacrificed in the process.

However, I should point out that if it were not for this sea wall, Galveston would have been devastated again, like it was in 1900 when 5,000 people were killed by that hurricane. The sea wall has served the community well. Unfortunately, they are very expensive and, of course, you do compromise and lose your beach in the process without ameliorating effects.

Finally, there is the approach of beach nourishment. This seems to be the way most of the coastal states are moving. The State of Florida has devoted $40 million per year to nourish its beaches. This is Miami Beach, Florida, where for 10 miles of shoreline the beach is built out about 300 feet wide as you can see in the process in the early 1980's. It, however, costs $65 million to nourish this beach. That is, move sand grains from point a to point b costs $65 million.

However, the cost benefit here certainly well justified in this case. My only question is, how many Miami Beaches can we actually hope to do. Clearly, we do not want this to happen to our shorelines or our lighthouses, but I wonder what the cost is going to be.

In summary Senators, I would like to say that it is expensive to live in the coastal zone, there is no question about it. In the future, with accelerated sea level rise, we expect those costs to go up quite high.

Thank you very much

[The prepared statement of Dr. Leatherman follows:]

IMPACT OF THE GREENHOUSE EFFECT ON COASTAL ENVIRONMENTS: MARSHLANDS AND LOW-LYING POPULATION AREAS

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PRESENTED TO:

United States Senate
Committee on Energy and Natural Resources

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Introduction

During the past century, worldwide sea level has risen about one-half foot. Along the U.S. mid-Atlantic coast, records show that the regional trend has been a doubling of this rate. In coastal Louisiana, it has been larger by a factor of 10 due to local subsidence. These substantial differences in the rate of relative sea level rise must be considered in relationship to human usage of the land in developing proper responses.

The general effect of sea level rise on coastal lowlands is to induce landward retreat -- beaches erode and marshes are lost. Most sandy shorelines worldwide have experienced recession during the past century. Such has also been the case along the U.S. coasts; historical data indicate that 90 percent of our sandy beaches are eroding. Accelerated sea level rise due to greenhouse-induced global warming will only increase erosion rates and the present shoreline dilemma. Also, coastal marshlands will be lost at ever-increasing rates, with the nation's marshes perhaps disappearing at the high rates of loss presently experienced in Louisiana.

Coastal Wetlands

Coastal wetlands account for much of the land less than 5 feet above sea level. These extensive marshes, swamps, and mangrove forests fringe most of the U.S. coastline, particularly along the Atlantic and Gulf coasts. These areas are vital to our fisheries industry, maintenance of water quality, and are important in coastal recreation.

There have been significant losses of wetlands due to filling marshlands for urbanization as well as through the construction of canals and waterways and, in some cases, diversion of river-borne sediments offshore (e.g., the Mississippi River). Most of these early practices have been discontinued on a nationwide basis in response to various federal and state programs. However, land losses in Louisiana are continuing at extremely high rates, amounting to thousands of acres per year.

Salt marshes exist in a delicate balance with water levels. With gradual sea level rise (due to local subsidence or worldwide changes), marshes can generally keep pace by trapping sediments in the water column and through accumulation of their own organic material (dead stems and leaves). However, an imbalance can develop if sea levels rise significantly faster than deposition on the marsh surface, eventually resulting in waterlogging and loss. With respect to sea level rise, coastal marshes can be broadly divided into backbarrier marshes, estuarine (brackish) marshes, and tidal freshwater marshes.

Backbarrier marshes occur along the bay sides of barrier systems of the Atlantic and Gulf coasts. Maintenance of these marshes in these dynamic environments is more a function of barrier stability than the pace of upward growth of the marsh surface, since sediment supplies are ample. For barriers that are rapidly migrating landward, there may be a net decline in backbarrier marshes as found at northern Assateague Island, Maryland. Elsewhere, marshes are exposed to the high energy surf as the barrier core has been completely eroded away (e.g., sections of the Virginia barrier islands, parts of the South Carolina and Georgia coasts). Coastal barriers along the Louisiana coast are eroding at extremely high rates, amounting to 30-50 feet per year. Loss of these protective landforms will result in increased loss of marshlands.

Brackish marshes are an integral component of major estuarine systems, such as the Chesapeake and San Francisco Bays. At present, most of these estuarine marshes receive adequate sediment to compensate for current sea level rise. This must have been the case during the last century since "natural" marsh loss has not historically been reported to be a problem. Notable exceptions include the Blackwater marsh (a major Atlantic coast flyway for waterfowl in the U.S. Fish and Wildlife Refuge system) and coastal Louisiana. In Louisiana, widespread wetlands loss is in part attributable to a sediment deficiency (the summation of a number of complex, human-induced factors).

Tidal freshwater marshes are located in the upper reaches of estuaries and other low areas where salinities are less than five parts per thousand. The effect of rising sea levels will be saltwater intrusion and displacement by higher salt-tolerant plants. Canalization for oil drilling activities in the Mississippi delta has had a dramatic effect on the local ecology in this regard.

Land losses in most wetlands result from a combination of mechanisms, with shoreline erosion at the seaward edge of the marsh being the most obvious process. This factor can be expected to accelerate with increased water levels, but shoreline erosion probably accounts for only a few percent of all marsh losses annually. Most marshes will be long since submerged before extensive shoreline erosion occurs.

A more probable catastrophic mechanism of marsh loss with a significant increase in sea levels (e.g., several feet) will be formation of extensive interior marsh ponds. These shallow-water bodies enlarge and coalesce at the expense of marsh vegetation in response to rapid coastal submergence. The magnitude of such losses can be quite extensive as shown by studies at the Blackwater Wildlife Refuge in Maryland, where over one-third of the total marsh area (about 5,000 acres) was lost between 1938 and 1979 by this process. These marshes are being lost because sea levels outpace the ability of the marsh to maintain elevation, ultimately resulting in root death of the marsh plants.

Beaches and Coastal Barriers

Sea level rise will have a different effect along various portions of the U.S. coastline, depending on such conditions as sediment supply and coastal configuration. It is possible to divide the coasts into physiographic regions for consideration of their response to relative sea level rise. For instance, conditions in Louisiana do not apply to the coast of Maine because the Mississippi delta region is very flat, undergoing pronounced compaction and subsidence, while northern New England is characterized by non-erodible cliffs and portions are experiencing regional (neotectonic) uplift. This general assessment of the U.S. coast's response to accelerated sea level rise is presented elsewhere (Responding to Changes in Sea Level: Engineering Implications, National Academy of Science Press, 1987).

The present rise in water level is a complex phenomenon, including local, regional, and global components. Shoreline position will respond to the cumulative effect of vertical motions, termed the relative sea level rise, regardless of the cause. Rising relative sea level tends to cause shoreline recession, except where this trend is offset by an influx of sediment (naturally by river-borne sand deposition or artificially by beach nourishment).

Rising sea level is accompanied by a general recession of the shoreline due to inundation or erosion. Inundation is the submergence of the otherwise unaltered shore, while erosion is the physical removal of beach material. Direct submergence of the land occurs continuously through time and is particularly evident in coastal bays. Submergence, however, accounts for only a small portion of the net shore recession along open ocean, sandy beaches and barriers.

The primary reason that a sea level rise would induce beach erosion is that natural beach profiles are concave upward; this geometry results in wave energy being dissipated in a smaller water volume than without sea level rise, and thus the turbulence generated within the surf zone is greater. The profile responds by conforming to a more gentle nearshore slope, which requires additional sediment to be eroded from the beach.

Most sandy shorelines worldwide have retreated during the past century. Progradation has been restricted to coastal areas where excess sediment is supplied by river sources or where the land is being elevated due to uplift in some northern regions (e.g., Maine). Human interference cannot be considered a primary cause of erosion since retreat also occurs on sparsely populated and little-developed sandy coasts. Such recession could result from an increase in storminess, but this trend would have to be almost worldwide to account for erosion on geographically dispersed sandy shorelines. Therefore, in view of the demonstrated general relative rise of sea level along the U.S. shoreline, the link between shore retreat and sea level rise is based on more than circumstantial evidence; it can be stated that the relationship is causal in nature.

In some areas, it is clear that human actions have caused substantial erosional pressures. Undoubtedly the principal problem has been construction of jettied inlets and deepening of channel entrances for navigation. Along shorelines with high rates of longshore sediment transport, these constructed features trap sediment at the updrift jetty and, if material dredged from the navigation channel is not placed on the downdrift beaches, cause an amount of downdrift erosion equal to the reduction in transport. At some Florida entrances, tens of millions of cubic yards of dredged material have been dumped offshore and thus are permanently removed from the beach. This has resulted in very high erosion concentrated downdrift of tidal inlet entrances.

Historical data (maps and aerial photographs) can be used to determine rates of shoreline change. Over one hundred years of record are available for the U.S. coasts from the National Ocean Service of the National Oceanic and Atmospheric Administration (NOAA). This accurate informational base has been utilized for large stretches of the coastline (including much of the U.S. Atlantic and parts of the Gulf and Pacific coasts) to determine historical rates of beach erosion and barrier recession.

The national (unweighted) average rate of shoreline recession is slightly more than one foot per year. Along the Atlantic coast, beach erosion has historically amounted to about two to three feet per year, with the Virginia barrier islands exhibiting the highest rates of erosion (tens of feet per year). The Gulf coast states are distinguished by having the highest average erosion rate in the nation (over five feet per year). While parts of the Florida panhandle are fairly stable or only slightly eroding, the deltaic coast of Louisiana is by far the most dynamic (15 feet/year of erosion on average). The Pacific coast is essentially stable on average, considering the fact that more than half of the shore is hard rock. Locally, there are severe erosion problems (e.g., Oceanside, CA), and winter storms have caused dramatic losses of very valuable property in recent years where the beaches are already quite narrow (e.g., Malibu during the 1981-82 storm season).

A number of techniques have been developed to project shoreline retreat due to sea level rise (see 1987 National Academy of Sciences report). Accelerated sea level rise due to the greenhouse effect will increase the erosion rate and cause stable beaches to begin eroding. Based upon the projected rates of sea level rise, it is estimated that sandy beaches will erode at two to five times their current rate. This portends major problems for low-lying areas, such as coastal Louisiana, and increased problems at such beach resorts as Ocean City, Maryland, where the historical rate of beach erosion has amounted to two feet per year. Many of the urbanized beaches along the East and Gulf coast barrier chain are already critically narrow and in need of beach nourishment to protect the existing buildings and infrastructure. Such is the case at Ocean City, Maryland, where a $30 million beach fill project is scheduled to begin next spring. Elsewhere, many other recreational beaches have been nourished (e.g., Atlantic City, NJ; Myrtle Beach, SC; Miami Beach, FL). The expected lifetime of nourished beaches will be greatly foreshortened by accelerated sea level rise, increasing the frequency and magnitude and hence the cost of such activities.

Responses

A significant portion of the nation's population lives within the coastal zone, with many buildings and facilities built at elevations less than 10 feet above mean high tide level along the shoreline. Presently, many of these structures are not adequately above existing water levels or located far enough landward to adequately ensure their survival and safety of the people during major storm activity. This hazard has grown increasingly apparent and serious along much of the U.S. East and Gulf coasts, particularly the highly urbanized sandy barriers, as relative sea levels have risen during the twentieth century.

Residential houses and other buildings have been drawn close to the water's edge as the beaches have eroded. In an attempt to insure that future coastal structures are built stronger and above the present 100-year flood levels, the Federal Emergency Management Agency (FEMA) has been charged with providing federal flood insurance to these properties. This flood insurance program was developed to address the problem of river floods, and later expanded to include open coast, beachfront communities. Today, properties worth billions of dollars are Federally insured, making this the second largest national liability after Social Security. Unfortunately, FEMA has only adopted the flood levels approach in establishing insurance rates, which works well in river floodplains, but does not consider the fact and importance of beach erosion. Eventually a stable building and a retreating shoreline will merge, and there are numerous places along the U.S. coast where houses are standing on the beach or in the water (e.g., Westhampton Beach, NY; South Bethany Beach, DE; Folly Island, SC; Sargents Beach, TX). FEMA needs to utilize the existing erosion data and future projections of beach recession to adjust their policies and insurance rates through the development of an E (Erosion) Zone.

There are three general responses to accelerated shoreline erosion: (1) retreat from the shore, (2) armor the coast, or (3) nourish the beach. The choice of a response strategy will depend upon a number of factors, including socioeconomic and environmental conditions. The decisions reached will likely be site-specific so that each area/community must be evaluated separately.

For highly urbanized areas, such as Miami Beach, FL or Ocean City, MD, the abandonment option is not realistic. The value of such beachfront property with high density and high-rise structures often approaches $100 million per mile, making beach restoration the most attractive alternative. Elsewhere, sea walls have been constructed to stabilize the shore and protect coastal communities from the ravages of major hurricanes (e.g., Galveston, TX). For eroding shorelines that are less developed, the decision becomes more difficult. Therefore, the costs and benefits of protection must be weighed against those of retreating from the shoreline.

Conclusions

1. Worldwide sea levels have risen about one-half foot in the past century. The rates have been variable along the U.S. coasts for a number of reasons, but have amounted to one foot per hundred years along the mid-Atlantic coast. The rate of relative sea level rise in coastal Louisiana is about 10 times greater than the worldwide average due to subsidence.

2. The general response of low-lying lands to sea-level rise is retreat via beach erosion and wetlands loss. Already extensive coastal marshes are being lost in Louisiana, and it is expected that many of the barrier systems on this deltaic coast will break-up and disappear in the next half century. Extensive salt marsh loss has also been reported in the Maryland Chesapeake Bay (over 5,000 acres lost at Blackwater marsh, mostly occurring during the past 40 years).

3. The prospect for coastal wetlands is bleak in light of existing conditions and projected changes (e.g., greenhouse effect). Marshes in Louisiana, for example, are not able to keep pace with relative sea level rise, and are presently being drowned in place. A rapidly subsiding land surface or accelerated sea level rise can yield similar results. There will be substantial losses of coastal marshes in the future (e.g., some studies project over 50 percent and perhaps as much as 80 percent loss by the year 2100 on a nationwide basis).

4. Over 90 percent of the nation's sandy beaches are experiencing erosion. Historical shoreline studies indicate a wide range in erosion rates (essentially stable to over 30 feet per year). The Atlantic coast average is between two and three feet of beach erosion per year, the Gulf coast

exceeds five feet per year, and the Pacific coast is stable on average (much of the shore is hard rock).

5. Accelerated sea level rise due to the greenhouse effect will at least double and perhaps quadruple erosion rates, depending upon which rise rate is actually realized.

6. There are three general categories of human response to shoreline recession: (1) retreat from the shore, (2) armor the coast, (3) nourish the beach. The proper response will be site-specific on a community or coastal sector basis due to large differences in environmental and socio-economic factors. The abandonment alternative is not realistic for highly urbanized beaches, like Miami Beach, FL and Atlantic City, NJ. For less developed areas along eroding shorelines, the decision becomes more difficult. Therefore, the costs and benefits of stabilization vs. retreat must be carefully considered as the cost in either case is likely to be quite high.

7. The apparent national desire to live in the coastal zone has long term and expensive consequences. The Federally-insured flood program is already burdened with billions of dollars of insured properties close to the water's edge. Accelerated sea level rise due to the greenhouse effect will further jeopardize these vulnerable properties, eventually resulting in massive destruction (without ameliorating action) during future major storms at great expense to the American taxpayer.

Senator **Wirth**. Gentlemen, thank you very much. Before getting into our questions, let me ask if any of you have comments that you might like to make on testimony given by the other witnesses? Any additions or disagreements, or do we have of a panel in agreement here?

Dr. Firor, let me just go down and ask if any of you have any comments that you would like to make?

Dr. **Firor**. I was very interested in Dr. Manabe's testimony. Syuki, do you believe that we are making rapid progress in understanding the regional features of the climate change?

We have all said at past times that that is very difficult, but you sounded more optimistic now. Do you think that we can begin to rely on the regional, what will happen in the middle of the United States or the middle of the Soviet Union now?

Dr. **Manabe**. Now, as I mentioned, the computational resolution of our model is very coarse, so that at present we can only talk about the very large scale features I emphasized such as mid-continental dryness.

If I am asked say, what exactly is the dryness change in the State of Ohio or exactly what the change is in the State of Wisconsin, we cannot say much at the present time. As you can see, the reduction of soil dryness is on a rather global scale phenomenon, the mechanism of which is a rather simple, straightforward. That basic mechanism is still going to be realized, that is the way that I feel.

I cannot say at this time the exact State by State breakdown, exactly how these climates are going to change. It takes a long time for the climate model to reach that stage.

Senator **Wirth**. Other comments?

Dr. **Firor**. I have no other comments.

Dr. **Blake**. I was curious, does your model include the other trace gases? You kept mentioning CO_2, but did it have the others in it and you just did not mention them?

Dr. **Manabe**. I think at present when we talk about greenhouse gases, we evaluate the relative importance of greenhouse gases very often and try to evaluate, based upon their direct importance relative to CO_2.

I was basically assuming that the other greenhouse gases have similar effects as carbon dioxide when I changed carbon dioxide. There are some evidences which support that statement.

Senator **Wirth**. Senator Murkowski.

STATEMENT OF HON FRANK H. MURKOWSKI, U.S. SENATOR FROM ALASKA

Senator **Murkowski**. Thank you, Mr. Chairman.

You asked me earlier, Mr. Chairman, if I had a statement. I do have a brief statement. First, let me commend you for holding these hearings. I think that the subject matter is of great interest to this Committee and virtually everyone in the coastal areas of this country.

It is a matter of my own commitment. I recall one of the first speeches that I made on the floor of the Senate in 1981, when I called for a higher national priority for scientific research on global climate changes, specifically the greenhouse effect. My particular interest, of course, is on the Arctic.

That was eight years ago, but in 1984 Congress passed the Arctic Research Policy Act, which I am sure that some of you gentlemen are familiar with. It was my first bill to get through the Senate. It was sponsored by the late Scoop Jackson, a good friend, and Senator Ted Stevens.

During the past three and one-half years, we have seen that act shift more scientific attention toward the polar regions, particularly the Arctic. As you know, we have phenomenas in the Arctic, such as Arctic haze and various other things that are causing us great concern.

You gentlemen spoke on the ozone hole; we have seen evidence of that in the Antarctic. We also have seen Arctic pollution from northern Europe and the global warming trend. We have obviously got a great deal to learn about these phenomena.

A significant amount of scientific research must be undertaken before we can know just what the greenhouse effect is, what we can expect to become of it, and what we must do as a consequence. I commend you gentlemen for your presentation in that regard.

It is my belief that we need more scientific efforts directed towards the Arctic, and I assure you that my colleagues in Alaska stand ready to help. My State already devotes a significant amount of its resources toward research in the Arctic.

At the University of Alaska, we have a logistic capability to support research and we have already collected substantial data and information to serve as a strong foundation for future research. This is, of course, one of the roles of the Arctic Research Policy Act.

Now that we have it in effect, I wanted to be sure to advise you gentlemen of the realization that that tool is in existence.

[The prepared statement of Senator Murkowski follows:]

STATEMENT OF SENATOR FRANK H. MURKOWSKI
COMMITTEE ON ENERGY AND NATURAL RESOURCES
UNITED STATES SENATE

HEARING ON GLOBAL CLIMATE CHANGE AND THE "GREENHOUSE EFFECT"
November 9, 1987

I'D LIKE TO COMMEND THE CHAIRMAN FOR HOLDING THESE HEARINGS. THIS SUBJECT HAS BEEN AN INTEREST OF MINE FOR QUITE SOME TIME.

IN MY FIRST SPEECH ON THE FLOOR OF THE UNITED STATES SENATE, I CALLED FOR A HIGHER NATIONAL PRIORITY FOR SCIENTIFIC RESEARCH ON GLOBAL CLIMATE CHANGES, THE GREENHOUSE EFFECT, AND OTHER AREAS OF STUDY IN THE ARCTIC. THAT WAS NEARLY EIGHT YEARS AGO.

IN 1984, CONGRESS PASSED THE ARCTIC RESEARCH AND POLICY ACT - LEGISLATION I SPONSORED WITH HENRY "SCOOP" JACKSON AND TED STEVENS. IN THE PAST THREE AND A HALF YEARS, THAT ACT HAS SHIFTED MORE SCIENTIFIC ATTENTION TOWARD THE POLAR REGIONS, PARTICULARLY THE ARCTIC.

TODAY, WE ARE HEARING ALARMING REPORTS ABOUT THE SO-CALLED "OZONE HOLE" IN THE ANTARCTIC, ARCTIC AIR POLLUTION, AND A POSSIBLE GLOBAL WARMING TREND THAT IS LIKELY TO BE MOST EVIDENT IN THE ARCTIC.

WE HAVE A GREAT DEAL TO LEARN ABOUT THESE PHENOMENA, AND A SIGNIFICANT AMOUNT OF SCIENTIFIC RESEARCH MUST BE UNDERTAKEN IN THE ARCTIC BEFORE WE'LL KNOW JUST HOW SERIOUS THE "GREENHOUSE EFFECT" IS, WHAT WE CAN EXPECT, AND WHAT WE MUST DO AS A CONSEQUENCE.

MUCH OF THIS SCIENTIFIC EFFORT WILL TAKE PLACE IN THE ARCTIC, AND I WANT MY COLLEAGUES TO KNOW THAT ALASKANS ARE READY TO HELP. MY STATE ALREADY DEVOTES SIGNIFICANT RESOURCES TOWARD RESEARCH IN THE ARCTIC. WE HAVE A LOGISTIC CAPABILITY TO SUPPORT RESEARCH, AND WE HAVE ALREADY COLLECTED DATA AND INFORMATION THAT CAN SERVE AS A STRONG FOUNDATION FOR FUTURE RESEARCH.

AND JUST AS IMPORTANT, WE HAVE THE ARCTIC RESEARCH AND POLICY ACT, AND AN ARCTIC RESEARCH COMMISSION IN PLACE TO HELP COORDINATE AND PRIORITIZE OUR NATIONAL RESEARCH EFFORTS IN THE ARCTIC.

THE UNITED STATES IS, BY VIRTUE OF ALASKA, AN ARCTIC NATION. AND I WANT TO IMPRESS UPON MY COLLEAGUES IN CONGRESS, AND AGENCY HEADS WHO MAKE BUDGET REQUESTS, THE IMPORTANCE OF FUNDING ARCTIC RESEARCH INITIATIVES AS A NATIONAL PRIORITY, NOT ONLY FOR THE PURPOSE OF UNDERSTANDING AND ADDRESSING "THE GREENHOUSE EFFECT," BUT TO ALLOW THE UNITED STATES TO ASSUME ITS RIGHTFUL PLACE AS A LEADER AMONG POLAR NATIONS.

THANK YOU, MR. CHAIRMAN.

FOR IMMEDIATE RELEASE November 6, 1987
CONTACT: Clare Lynam (202) 224-9306

ALASKAN DINOSAURS THRIVED ON SUNNY NORTH SLOPE

Washington, D.C. -- Imagine sunning yourself in a balmy, tropical forest -- on the North Slope! There's evidence now that it was once possible.

An off-shoot of the exploration for oil and gas in Alaska is yielding rich rewards for scientists. Paleontologists are now combing the North Slope, looking for the remains of the plants and animals that thrived in Alaska 65 million years ago. One of those scientists, Dr. William Clemens of the University of California, Berkley talked recently on Senator Frank Murkowski's weekly radio program.

Dr. Clemens said studies done by the U.S. Geological Survey (USGS) and some of the faculty at the University in Fairbanks "indicate that the North Slope of Alaska was much closer to the North Pole than it is today. Surprisingly," he said, "the evidence indicates that even at that high northern latitude it was much warmer. (There was) a lush vegetation covering the North Slope and a variety of animals including at least three kinds of dinosaurs living in the area."

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The common dinosaur, Dr. Clemens said, was what is called a "duck-billed dinosaur." Clemens said fossils indicate this animal walked on its hind feet and was probably a plant eater. "The expansion on the end of its snout that suggests it was adapted to cropping large mouthfuls of vegetation," he said.

These animals and plants have, over the years, decomposed into the large deposits of coal, oil and gas now found on the North Slope. The coal, Clemens said, "testifies to just how much vegetation grew there and also the efficiency with which this vegetation was converted to coal."

Further exploration along the Colville River by scientists of the USGS, have also turned up part of a fossil turtle and a different kind of dinosaur -- a Stegosaurus, which Dr. Clemens described as, "the four legged form with the frill over the back and three horns sticking forward."

"We're beginning to get a picture of a diversity of life there, Dr. Clemens said, but he added, "I must stress that this is in entirely pioneering stage of investigation."

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Clemens said Alaska's dinosaurs, "didn't migrate with the seasons, but were there year-round. One of the pieces of evidence that we have that suggest this is that we're finding kinds of dinosaurs that lived in Alberta at this time are very closely related to kinds that lived in China and Mongolia. They must have been moving back and forth across Alaska and it's an awful lot to ask of a dinosaur to hot-foot it from Alberta to Mongolia in one summer, so the probabilities are high that there were resident populations (of dinosaurs) in Alaska some 65-70 million years ago," he said.

The Senator asked Dr. Clemens to explain how he knows that the North Slope was closer to the North Pole than it is today. He also asked: if it was closer, how could the climate have been warm enough to support life?

In response to the first question, Clemens said the evidence on the position of the North Pole "comes from measuring fossilized magnetic signals in rocks. You have these ancient compasses pointing toward the pole," he said. The North Pole, at the time these dinosaurs were living, was not far off Point Barrow according to Dr. Clemens.

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On the question of warmth he says, "there are a couple of suggestions. One is that the many shallow seas covering a variety of continents, could have acted as heat traps picking up the sun's radiation. The currents would have circulated this warm water from the central part of the lower-48 up to Alaska by a sea-way that connected the two areas.

"Another suggestion is that the Carbon Dioxide content of the atmosphere may well have been much higher than it is today. So you get one of these 'green-house effects' where there would be a very high efficiency in capturing the heat from the sun's radiation just warming up the entire atmosphere." He said there is a possibility that a combination of these things would have led to a much warmer world climate with much less difference in temperature between the equator and the Poles than we see today.

Dr. Clemens has called his experience working with Alaska scientists, "both scientifically and personally a rewarding experience." Senator Murkowski invited him to come back to Alaska and added, "I'm sure those at the University of Alaska - Fairbanks will put out the hospitality mat when you do."

# # # # #

Senator **Murkowski**. My question, Mr. Chairman, involves that portion of the presentation concerning the greenhouse effect, the warming trend, and the scientific evaluation that indeed some 65 million years or thereabouts we had some unique phenomena on earth.

Dr. Clemens, who was a palentologist at the University of California and has been a student of the warming clients, issued a report with regard to the climate 65 million years ago that were in existence near the north pole.

According to his reported scientific evaluations those climates which resulted in today's significant coal deposits, some of the largest deposits in North America, significant oil shale, oil sand deposits were extremely warm. One of the reasons may have been a significant amount of carbon dioxide in the area which, indeed, created a greenhouse effect.

According to Dr. Clemens, those climates even supported three species of dinosaur that roamed the Arctic and were not migratory, but indeed stayed there year around.

I am wondering if anyone would care to comment on whether indeed carbon dioxide greenhouse effect may have been in existence 65 million years ago to cause what we know is there today, and what would have caused the decrease in the cooling of that climate?

It is my understanding too that Dr. Clemens indicated there was some reason to believe that there may have been interior water flow that created a heat trap that moved warmer temperatures from the south up to the north and created this lush vegetation.

I guess the real question is, how do you explain the potential high content of carbon dioxide at that time and the fact that it left and now we are seeing it come back as a consequence of the reasons that you have identified collectively here today?

Dr. **Manabe**. I am not an expert in geo-chemistry, but I can tell what I know. Professor Banner and his collaborator at the Yale University have been running a geochemical cycle model, which extends from the time you are talking about through the present.

According to his discussion, their model indicates that CO_2 concentrations rose during that era particularly, the crustacean era just before this extinction time you are talking about. The climate was very warm and the CO_2 may have been indeed higher, much higher, maybe factored several times than the present.

One of the important factors which controls these long times, we are talking about millions, hundred millions time scale—is the sink of CO_2 in the atmosphere due to the weathering which fixes CO_2 into the rocks. The source of CO_2 for the atmosphere is out-gasing from the Earth's interior and during that time they assert that the rate of continental spreading was faster.

Therefore, this source from the interior was larger, therefore, CO_2 concentration was indeed higher. Similar research was done earlier by Russian Scientists, Ronsv and Budyko so that there is speculation about the possibility that greenhouse gases were indeed higher at that time.

Another interesting thing is that latest issue of Nature indicates that from air bubbles trapped in the Antarctic ice sheet, carbon dioxide concentrations during the last glacial maximum and other glacial time were substantially lower than present.

This is talking about much later time, only the last few million years. The time of dinosaurs is 100 million, years ago, so it is a different time scale. But, the evidence from the Antarctic ice or Greenland ice indicates that carbon dioxide has, indeed, changed during geological time and that its fluctuations during the recent period are closely related to primate fluctuations.

Senator MURKOWSKI. Could someone compare then what the ozone condition was if, indeed, there was a high level of natural occurrence of carbon dioxide at that time?

I am just trying to get a relationship here or if we do, indeed grant, that there was high concentrations of carbon dioxide which caused this extraordinary vegetation in northern latitudes.

If carbon dioxide has an effect on the ozone layer, what was the comparison then? Perhaps someone else could comment.

Dr. BLAKE. I will comment on that. I think that the main reactions that are used in the models in predicting an increase let us say in ozone with respect to an increase of carbon dioxide up in the stratosphere, is with respect to the chlorine removal process of the ozone. In other words, the chlorine reacts with ozone and forms something, and then that goes through another reaction.

It is this reaction that has slowed down as the temperatures change in the stratosphere. I think that for today's atmosphere, it is a pertinent question.

For the atmosphere of let us say 1 million or even 100 years ago, there was so much less chlorine in the upper atmosphere that the ozone levels were not dictated to as much by the chlorine. So, a warming or cooling effect of the stratosphere, I think, would have very little effect on the atmosphere of even 100 years ago.

Senator MURKOWSKI. Does anyone else care to comment on the national occurrence of the increased carbon dioxide?

Dr. RAMANTHAN. I would like to touch on the point which has not been addressed here so far, and it sort of reflects on Senator Murkowski's point of the connection in the CO_2 and ozone change.

When we increase the carbon dioxide, we were talking about the greenhouse effect and warming of the lower atmosphere. Carbon dioxide also leads to a substantial cooling of the upper atmosphere, upper meaning the region of the atmosphere above 15 kilometers.

Now the connection between this cooling and ozone comes because the reaction in the stratosphere which leads to the production of ozone and destruction depend on the temperature in such a way that when you cool the stratosphere, you may lead to more ozone change.

However, that projected increase in the stratospheric ozone into the CO_2 cooling is much, much smaller than the destruction effect of chlorine coming from fluorocarbons.

Now going back to your question about the crustaceans when geochemists suggest a larger amount of CO_2, there would not be any reason to expect large changes in the ozone. There should have been some changes in the ozone.

Dr. FIROR. May I comment further on this question? It is very difficult to reconstruct what was happening 65 million years ago. Climatologists have been fascinated, in fact, by one fossil that would found in what is now the middle of Siberia of a tree species that cannot tolerate freezing weather.

This then, requires some explanation, either who dug the fossil made a mistake or it was quite warm if it never got to freezing there in the middle of Siberia.

One approach has been to try to work backwards and say let us move in our models and our calculations that we have heard so much about, move the continents around because we know they move. Move them back to where they were 65 million years ago and see if that makes the earth warm. It makes it a little warmer, but not nearly enough.

This leads to the conclusion, you have to add something else and the easiest thing to add is carbon dioxide. That is a different set of inferences that say you have to have more carbon dioxide.

This period though has relevance to today and what we believe about what will happen in the next 100 years in the following way: There has grown up a school of thought that there may be something in the biological system of the earth that controls the climate; that living things like to keep the climate pretty much the same; and, therefore, there may be less reason to worry about the future because plants and animals, bacteria and so forth will change in ways to regulate the climate.

The existence of a period 65 million years ago when there was obviously a thriving biosphere, lots of plants and animals and dinosaurs when the temperature was that much warmer so that the sea level was hundreds of feet higher than it is today, so the temperatures were many many degrees is also a single point saying that if the biology controls the climate it does not do a very precise job. It can let the temperature range over a very wide range and, therefore, we cannot sit back and rely on the biosphere to keep us out of trouble. We probably have to keep ourselves out of trouble.

Dr. HANSEN. I would like to make one additional comment with regard to the use of these ancient climate studies and the knowledge of CO_2 at these ancient times.

It is difficult to say exactly the causes of the climate change that long ago, 65 million years ago. But on the other hand, one piece of evidence which has become obvious in the 1980's and has changed our view of how certain the CO_2 climate changes are, is the measurements of the CO_2 changes in the past 100,000 years. There have been ice cores taken in the Antarctica and Greenland, and the bubbles of air trapped at different times in the past 100,000 years show us how CO_2 changed. It went up and down several times during the past 100,000 years and the climate changes are remarkably well correlated with the CO_2 changes in that time period.

It has given us a very good test of our understanding of how sensitive the climate system is to the CO_2 changes. That is one of the reasons why we are much more confident in the model predictions now than we were, say, eight years ago.

Senator MURKOWSKI. I do not want to take up too much time, but lastly, is it fair to say that the reason it went warm 65 million years ago to cold is because of the lesser concentrations of CO_2? Obviously, that is what happened.

Dr. MANABE. I think that the years from 65 million to present, that is more speculation.

Senator MURKOWSKI. Well, we know the dinosaurs were up there because we found them. We know that the north pole used to be closer to the Prudhoe Bay Area, the Canning River and the North Slope, because of different magnetic——

Dr. HANSEN. Yes. However, the explanation——

Senator MURKOWSKI. The coal is there and the oil is there.

Dr. FIROR. Which attributes that warming in these areas are still speculative aspects of our science. However, I think our more recent past, which Jim Hansen just emphasized that last 150,000 years during which period we got much better evidence of carbon dioxide concentrations. That period we can use for the variation of climate model.

As a matter of fact, geologists got together and made an intensive study of the climate and the environment of 18,000 years ago which was the last climate maximum, and we are using more and more of that climate which is drastically different from now. We use that as a variation tool over a climate model as Jim Hansen emphasized.

A more recent past probably gives us much, much promising data for the variation of data and we are very much encouraged by this.

Now, the past is still more of speculation than the scientific evidence, but it is a very interesting possibility which people are discussing.

Senator MURKOWSKI. Mr. Chairman, I could go on all day, and you have another group of witnesses.

I would like to have my opening statement entered into the record.

Senator WIRTH. Without objection.

Senator MURKOWSKI. And, a statement on Alaska dinosaurs thriving on the sunny North Slope depicted 5 million years ago.

Senator WIRTH. Without objection.

Gentlemen, is it my understanding that there is, at this point, no significant disagreement in the scientific community about the concentrations of CO_2; about how fast concentrations are increasing; and, that these measurements have been taken over a period of time and those measurements have been taken in a very geographically dispersed area so that we see this geographically spread out over a 25-year period of time; and, that there is broad consensus that what you are testifying here to this morning is happening; is that right?

Dr. BLAKE. Correct.

Senator WIRTH. We are not talking about something that is highly speculative; we are talking about some pretty hard data? Is that correct? You are all nodding in agreement.

Dr. BLAKE. There is good agreement among the measurement groups to the trends that have been shown today. I say, very good agreement.

Senator WIRTH. Then, can one safely say—maybe I will ask you, Dr. Firor—safely say that some climate changes and perhaps some potentially great climate changes are inevitable; is that correct?

Dr. FIROR. When you move from the measurement of increasing carbon dioxide into the atmosphere to projections of what is going to happen, the statement is softened only a little bit. There is a strong scientific consensus that the models are telling us the right answers, and that therefore, if the greenhouse gases continue to increase in the atmosphere as seems likely, that indeed the climate will warm.

The range of disagreement is described by Jim Hansen as some people think it will warm a little faster and others not so fast, but today the scientific community has gathered around those results and are saying those are the ones that we put our bets on.

The chances that we are really wrong, that we have forgotten something that will make it cool or will make it zero, are shrinking fast and are now basically negligible.

Senator **Wirth**. Before we get to the ramifications, I want to make sure that we are all in understanding about the assumptions and the science.

Let me ask you all, maybe you have had experience with the Department of Energy. Does the Department of Energy share your view that we can place strong confidence in the climate models that predict this kind of global warming? Do any of you know?

[No response.]

Senator **Wirth**. You do not know? Nobody knows?

[No response.]

Senator **Wirth**. Have any of you had any dealings with the Department of Energy about the data that you are presenting this morning?

Have any of you ever talked to the Department of Energy about this? [Laughter.]

Senator **Wirth**. Does the Department of Energy talk to anybody about this sort of thing?

Dr. **Hansen**. I think we should make clear that the Department of Energy is, of course, the lead agency for carbon dioxide climate research, so we are all very familiar with the Department of Energy.

I think, and perhaps the other panel members might correct me if they do not agree, I would say the Department of Energy is less convinced of the certainty of long term climate change than perhaps represented by this panel.

Senator **Wirth**. Wait a minute. It seems to me that we just established Mr. Hansen, that there was consensus in the scientific community on the breadth of the data; the accuracy of the data, the geographic dispersal of the data, and, with some slight modification, the fact that the long-term trends are going to change.

Now, you are telling me just the opposite, that there is not this kind of consensus.

Dr. **Ramanthan**. Let me try to address that. First of all, there is a consensus as far as the rate of the increase of the trace gases and the global representation. All I can say is, I would be very surprised if the Department of Energy disagrees with that data. I do not think that is the issue.

The second thing I would say, which I think the Department of Energy also hopefully is comfortable with it, is that we feel reasonably certain that given this increase in these gases that the warming, the global warming is inevitable.

I think what is at issue and what there may be disagreement with, and I do not think it is inconsistent with what was presented, is the magnitude of that warming and the timing of that. That is where the argument is.

Senator **Wirth**. Is that the only area? The magnitude and timing is the only place of disagreement? Would you agree with that, Dr. Hansen?

Dr. **Hansen**. Yes, but that is essentially everything. If the magnitude is small, then it is not much of an issue. So, to say that the only disagreement is magnitude and timing leaves a very wide area.

Senator **Wirth**. They do not agree with you all on the magnitude of the increase or the rate of it; is that right?

Maybe I am dense, but I do not understand. If there is broad agreement in the scientific community and you are telling me that the Department of Energy does not agree with you, what is going on here?

Are you all wrong or is the Department of Energy not listening, or what is happening?

Dr. **Firor**. When you say the Department of Energy, of course, you are reaching well outside the scientific community. [Laughter.]

Senator **Wirth**. That is a pretty devastating comment itself.

Dr. **Firor**. Let me explain that. The Department of Energy contains and supports many good scientists, modelers, some famous ones, for example, Livermore Laboratory and so forth, who participate in creating this kind of model, that I think could be counted in the general consensus that we have referred to.

The Department of Energy has been much more complacent about one, the inevitability of the change and two, about whether or not people could adapt to it. It is on that side rather than on the modeling per se, that I think you will find the major difference.

I do not know of a climatologist modeler within the Department of Energy or any of their national laboratories that comes out and says no, it will only be one-half degree for a doubling or anything of that sort.

I do not think there is any real disagreement about the basis consensus that has been described here this morning. Perhaps a difference in attitude toward what that means for the country and what that means for the world, or whether techniques are available for doing anything about it. That is what I meant.

Senator **Wirth**. Would any of you have any comment on Dr. Firor's use of the word "complacent" in approaching this? We have a difference of magnitude, a difference in interpretation and timing and perhaps they are being complacent about this. We are now at the nexus of scientific knowledge and public policy. It seems to me that that is what we are beginning to skirt right now, which is where I want to move this if we can.

Dr. Manabe?

Dr. **Manabe**. I was unaware of the Department of Energy's—their basic thrust—is different from what is presented here today. If you look at recent state of art report from the Department of Energy, what they did is summarizing Jim Hansen's results, my results and all of our results and then try to make sense out of them and try to see the range of uncertainty.

I do not see how that can be inconsistent with what we have talked about today, and the Department of Energy has a summary statement. And also, International Institute of Stockholm recently published a summary in the international arena and they state the range of greenhouse warming is between 1.5 and 4.5 degrees centigrade. The total greenhouse doubling from the beginning of this century will be doubled in the first half and the effect of the ozone will be realized somewhat later.

I am not aware there is such a disagreement. As a matter of fact, Department of Energy summarized the work we have done in the recent state of our report.

Senator WIRTH. Let me see if I can continue this a little bit. From Inside Energy on November 9, 1987, quote:

> Available models for studying the effects of rising carbon dioxide levels in the atmosphere are inaccurate when applied to continental or regional phenomenon, DOE's top carbon dioxide scientists said last week.
>
> Federick Koomanoff, director of carbon dioxide research said the current scientific base is insufficient to understand or predict climate or vegetative responses to elevated atmospheric carbon dioxide.

Do you all agree with Dr. Koomanoff?

Dr. FIROR. If you read that carefully, they are talking about the——

Senator WIRTH. I was trying to read it slowly.

Dr. FIROR. The response at any particular location as I understand what you have read.

Senator WIRTH. When applied to continental or regional phenomenon.

Dr. FIROR. Right. Therefore, the uncertainties that have been discussed here this morning that one cannot be sure that the State of Iowa will proceed in a certain way certainly limits your ability to predict the impact on vegetation or water resources in that smaller region.

Now, there is the word continental in there, and I am not sure what that means. But there is, I think, considerable region for discussion and improvement of the models in the manifestations in particular spots on earth.

Senator WIRTH. Would you all suggest on the basis of what you know as scientists and on the basis of what you know is occurring at DOE, that there ought to be significantly greater research going on this area as Senator Murkowski was suggesting? Is this more micro-research if there is agreement on the macro-phenomena, if that is the right way to put it?

Dr. BLAKE. I would like to comment. I feel a little bit uneasy whenever I hear something like this that just talks about carbon dioxide. Maybe it is because I have devoted the last decade of my life to other trace gases.

But am I safe in assuming that these calculations that are being talked about in this particular article, do they not contain the other trace gases? I am not familiar with this particular article.

Senator WIRTH. What I am reading from is refers only to carbon dioxide. It is talking just about the carbon dioxide.

Dr. BLAKE. Right. And, I think Jim Hansen and the rest of the panel members would agree that at this point, Jim's data indicate that the warming due to carbon dioxide and the warming due to the rest of the trace gases, is fairly comparable.

So, to use a model that would just have carbon dioxide, pretty much invalidates the prediction.

Senator **Wirth**. Are not the policy issues of this very significant? If in fact you are correct, if what you are saying is correct, if in fact the magnitude is well understood and if in fact this is occurring very rapidly as I think all of you have suggested, therefore, what we do in the United States as the largest industrial nation, as the largest consumer of energy, what we do has a significant impact on that.

What we have to do is related to our policy on energy consumption. What we do related to energy consumption is in part due to what we as a government do to encourage one or discourage another form of energy; is that not all correct?

If that is correct, therefore, would not the Department of Energy have a responsibility—we are going to be hearing from them—would they not have a responsibility to come up to us to say that it is folly to burn more coal, it is folly to open up Anwr, it is folly to cut nuclear research or it is folly to continue our lack of emphasis on solar.

Are there not significant implications for how public monies are spent and what energy directions we take; is that not the case?

It seems to me, just listening to all of you and thinking about the Department of Energy, it all seems to follow quite logically does it not?

Dr. **Firor**. As I touched on in my opening remarks it is a well studied and frequently repeated observation that the quickest, cheapest, best, easiest and most cost beneficial thing to do about energy now both on the point of view of energy supply and climate change, is to move quickly towards more efficient use of the energy we have.

End use efficiency can gain us a lot. If you read the reports, the estimates of what it can gain us have been increasing faster than any greenhouse gas. So that it is now solid, reliable conservative economists who are saying that yes, we can see our way clear to cutting the fossil fuel use in the United States by 50 percent; that by using efficient ways of employing that energy; deciding on what we want to do and how to do it with the most efficient processes, is an effective and cost beneficial step.

I have for some time been somewhat dismayed to see that the Department of Energy spends quite small sums on techniques for end use efficiency improvements, and quite large sums on subsiding some of the most expensive energy techniques that one could imagine.

From that point of view, it seems to me that these, not just the carbon dioxide problem but the whole energy supply problem, points to a reassessment of some of those priorities.

Dr. **Ramanthan**. Senator, I would like to make a correction. You suggested that there is an agreement amongst us on the magnitude of the warming. Maybe it slipped through the discussions. There is a three-fold uncertainty, even in the global warming.

For example, if you say you double the carbon dioxide, what is the magnitude of warming that you expect. What we can give you is not one number but a range, and that range is somewhere between 1.5 to 4.5 degrees centigrade. As Dr. Manabe pointed out, there is a consensus among this group on that range as amongst DOE.

The DOE state of the art report which was released three years ago came out with that range. So, that is where I think a value judgment comes in which of these ranges you want to take.

If you stay in the lower end of the range, then you would get a perception that the problem is marginally important and maybe we can wait and see how this warming proceeds. If you take the upper range, which is what is given out by the most comprehensive of our climate models such as Hansen's and Manabe's, which we call three dimensional climate models, these indicate a doubling of the carbon dioxide with a 4.5 degree warming.

So when I suggested there was an agreement on the warming by the magnitude, we are arguing in that range between 1.5 or two to five.

Senator WIRTH. If we were to take the lower range and assume the lower range for the purposes of public policy decision and are wrong, what kind of gratitude will we receive from our grandchildren and great grandchildren for having made that choice?

Dr. RAMANTHAN. I personally am recommending that you take the lower range. If I take my hat off as a scientist and testify as a citizen, I believe we take the upper range and be on the cautionary side, for the precise reason you just mentioned.

Senator WIRTH. I am going to come back to the noncarbon dioxide issues as well, which I think are significant as they relate to other agencies.

If we might finish this out—the implications of this for the Department of Energy and for national energy policy, which is the handle that we have in this particular Committee.

Dr. Hansen.

Dr. HANSEN. Could I show one graph which shows that even if we take the lower end of the range, if we look at temperature variations over the past 150,000 years, you see that it has never been more than 1 degree centigrade warmer than it is today.

So that, even if we took the lower end of the range of 1.5 degrees centigrade as a likely warming due to doubling of CO_2, that would take us outside the range of human experience.

So, there is agreement that there will be climate changes which will be very important.

Dr. MANABE. I would like to respond to the reliability of the hydrologic aspect of the change which I presented. As I discussed during my presentation, we cannot talk about hydrologic change in very fine regional scale because the computational coercision in the model.

Of course there is a statement by Dr. Koomanoff also that the national scale may not be reliable. What happened is that when the Department of Energy made a comparison among various results, there were discrepancies among the results of various experiments and numerical experiments.

So Dr. Koomanoff's statement may be a fair statement in light of the discrepancy which existed at that time. But the more recent results seem to be very similar to what we have presented. Based upon the physical mechanism, I am quite certain that this kind of thing should happen.

Now however, in terms of the hydrologic change, I think it is more difficult to pin down and get unanimous agreement than on the warming issue itself, which is more robust than hydrological change. It is quite natural that we have more disagreement on this issue than on global warming at the present time.

This is, I think, a major reason why we have to enhance more of the research activity particularly, we have to improve the processes which are incorporated in these models.

Senator WIRTH. Dr. Blake, let me go to your area of expertise. If you were to follow the same line of questioning that I was pursuing earlier related to the Department of Energy and carbon dioxide, would there be broad agreement say within the EPA or the State Department about the date that you were presenting this morning?

Dr. BLAKE. Yes. I believe that there are really no discrepancies in the experimental, the actual measurements that have been conducted by our research group or by other national agencies.

So, like I say, there is no reason to disagree with the data that have been presented today. It goes from my ballpark into Jim's where it goes from the actual analysis into the modeling.

Senator WIRTH. The next two questions are one, the need for greater research in the area that you represent—and Dr. Leatherman, this might get into your area. That is one. The second level of questions comes in at the areas of policy being pursued by EPA, NOAA, Department of Agriculture, Department of State.

Are they adequate to the task that we face? By way of comparison to point out the parallel with the earlier questioning related to the Department of Energy, perhaps we are pursuing a set of policies that are mutually exclusive of the goal of eliminating or at least slowing down the growth in carbon dioxide concentration.

Is that the case with these other agencies as well, relating to the other gases that you were testifying about this morning?

Dr. BLAKE. First I will say that the research that is being done in this particular area of trace gases continues. One of the slides that I showed was fluorocarbon 113, which up until just a few years ago was not even considered as an important trace gas because it was at such low concentrations.

The field of analysis, it is important to continue that and to increase the time and effort devoted to it, to look for other species that are actually increasing in the atmosphere that someone like Ron would then determine were important as far as greenhouse gases.

I will not go into the ozone layer problem right now, but it is a dual problem that we have. Yes, more research needs to be conducted in just the trace gas fields, not only to observe new compounds but also just to watch and monitor and see if there is a falling off or an increase in some way among some of the other trace gases.

Among the agencies that you mentioned, I guess maybe I would first comment on, since I did not get in on the DOE, I will admit that I know very little. I work in the lab and I do this analysis and I go around the world and take the samples, so I am not really familiar with a lot of the policy.

It would seem to me that within the last few years, there has been this increased emphasis in the greenhouse warming. That is because Jim is putting more species into his model that would accelerate this eventual greenhouse effect, the doubling of CO_2 that is talked about that will occur within the next 200 or 300 years predicted this warming and allowed the lawmakers or everybody in general, I guess, a comfortable cushion.

The prediction was that it was our grandchildren's children who would be effected by this global warming. Now we put in a large number of other trace gases and all of a sudden it is not just CO_2. An effective doubling of the CO_2 has occurred in the last five years because we have increased the absorption properties of the atmosphere.

So now this 200 or 300 year cushion that we had has now been pulled out from under us. Like I say, that is why there has been this concerted effort in going into the models and predicting using as much data as we have.

So, I think maybe the Department of Energy to this point, I am not saying that they are—I mean, I will say this just because I am ignorant to the fact. I am not saying that they are buying time in making a statement like this, but I think that they have, as I say, have had this comfortable cushion of a number of years to work on the problem and now it has been cut drastically.

Anyway, that is my CO_2 statement. Do you want me to address as far as what the EPA and other agencies are doing, I think that the protocol in Montreal that occurred a few months ago is a good direction to be heading. It is not just the United States but 29 or so other countries that are involved in this.

I realize this is the U.S. Senate and not the world Senate, and a lot of changes need to start here in the United States before they can go to the other countries and show them the way, so to speak.

This is a global problem, and the fact that we are the major consumer of energy and we produce more of these trace gases in some ways than other countries, I think that it is our duty as a global leader to also lead in the fields of pioneering new ways for energy management or in trying to reduce these trace gases, the fluorocarbons especially because of the dual effect of the ozone layer.

I hope that the policymakers see fit to continue along the lines of Montreal and maybe even constrain the production of some of these extremely long lived species and cut their production weight back. Because we can then buy some more time if we cannot find out or try and come up with energy alternatives, at least we can cut back on these other greenhouse gases.

Senator **WIRTH**. Do any of the others of you have comments on the research level or second, what the implications are for the agencies involved other than DOE?

Dr. **RAMANTHAN**. I would like to point out when we talk about the other greenhouse gases, some of the increase like methane and N_2O is not totally unrelated to energy use. They all come from fossil fuel combustion. Carbon monoxide, the increase in NO are suspected to contribute to one of the sources for the increasing of methane as well as the tropospheric ozone.

So even when you talk about the non-CO_2 trace gases, I think it might come under the purvey of the Department of Energy, at least in terms of fossil fuel combustion.

Dr. **Blake**. Something that I had expected to talk about during my testimony but neglected, was something that I think is extremely important with respect to the ability of the atmosphere to cleanse itself, and that has to do with hydroxil.

This is a radical that floats around the atmosphere at very low concentrations, but is sort of the garbage disposal or vacuum cleaner of the atmosphere. The CO_2, the carbon monoxide that Ramanthan has alluded to which is a product mostly from incomplete combustion in fossil fuels, is possibly rising by 1 percent or so per year.

Methane and carbon monoxide are believed to be the two most important gases that regulate the steady state concentration of hydroxil. In other words, if you increase methane and carbon monoxide by a factor of two, you can effectively lower the amount of hydroxil by a reasonable amount.

So by increasing the carbon monoxide due to fossil fuel burning and methane which is part from fossil fuel but also other biogenic but under human control, what we are doing is we are increasing the ability of the atmosphere to remove hydroxil. Hydroxil is the one thing that removes hundreds, I mean, a lot of species some that were covered today, a lot of the alternatives to the fluorocarbons that have been proposed.

Fluorocarbons, once we added hydrogen to them, can now be removed from the atmosphere by hydroxil attack if we have effectively lowered the amount of hydroxil in the atmosphere. All these gases that are now suppressed in concentration because of the removal in the atmosphere by hydroxil will be allowed to build up a little bit.

So, I think that this is a problem that is potentially far reaching and very damaging. Therefore, if we cannot control carbon monoxide which is the main species that controls hydroxil, that maybe along the way we can also cut down on the CO_2 and just in an energy efficient system.

Senator **Wirth**. Dr. Leatherman, if you were sitting down and talking to the next Secretary of Defense, what would you say to him about the implications of the rise in oceans for our national defense policy?

What should he be worried about? Should he be coming up to us saying we ought to be doing a different kind of research program, we ought to be changing the way in which our Government focuses various aspects?

Dr. **Leatherman**. There was a recent report by the National Academy of Sciences called "Implications of Rising Water Levels." I was a member of that committee that wrote that NASA report.

In their, we talked about ports, harbors, and other installations. For those areas, I think you are largely talking about the Navy here perhaps, and other waterborne installations.

It turns out that there is not going to be as much problem there as other areas, because the technology changes so rapidly. If you look at ports of today and how they worked 20, 30, 50 years ago, the containerized technology has really changed all of that.

So, I think that is probably the least area concerned overall in that regard.

However, as you probably know, some areas are so low that if you bring sea level up a foot or two, you are going to have problems with drainage, and of course, other things with hardened structures in terms of backing water up. It would be more difficult, but I do not see that as a critical problem.

I doubt that the Navy is going to be the first to have problems. I think that there would be a lot of other areas, and particularly, these urbanized areas built right along the shoreline are really the ones at risk.

Senator **WIRTH**. The Secretary of Agriculture might be more concerned than the Secretary of the Navy?

Dr. **LEATHERMAN**. I think he probably would, in terms of the whole issue of changing global climates.

Senator **WIRTH**. Do we know, in the agricultural area, if different methods of agriculture or different kinds of agricultural products would be adaptable to the changes that you all suggest are going to occur?

Dr. **FIROR**. I have asked that question of a number of agricultural specialists at schools around the country. They are a confident lot of people. They say, look what we have been able to do in raising yields of most of the major crops over the years.

We can adapt over a pretty wide range of conditions, given just a little warning. We can design crops that will do better in slightly dryer, slightly hotter, slightly cooler environments. When you press them and say what are the limits to that, where do you really get in trouble, the answer that you get is very complicated.

In order to adapt indefinitely to a changing climate, they have to make assumptions about availability of irrigation water, availability of various chemicals, whether these chemicals can be used indefinitely without building up to unpleasant levels. They feel that there are some real limits, but that we have not come up against them in a hard way yet.

You can see that a farmer who lives at the northern edge of the range of a certain crop where the growing season is just long enough and in some years the crop is lost, that farmer might enjoy a warming that gives a slightly warmer climate and a slightly longer growing season.

But if the climate change goes on at the rate which these calculations indicate, it is likely he will be forced to change crops pretty soon because that crop will lose its relevance to that particular location. The farmer will face the choice of changing crops, learning a new kind of agriculture or migrating with the climate, which is not really a practical alternative in this day and age.

So, agriculture will be affected initially. It will not be clear whether the loser or the winners are more frequent, but in the long run it will touch all the middle latitude farmers.

Dr. **BLAKE**. I would like to comment on some of the less accessible areas than farmland. First of all, studies indicate that if we increase the amount of carbon dioxide in certain studies, that plants generally thrive. I mean, if you increase it by a certain amount, plants will benefit by increasing carbon dioxide.

So, if you look at it just from that point you say good, let us increase carbon dioxide. However, not all plants benefit at the same rate. Rice and corn benefit if you double carbon dioxide one benefits 40 percent and one 20 benefits 20 percent. In other words, the amount that is grown is not the same.

A concern is that in these nonagricultural situations whether they be forests or whatever, in very fragile ecosystems, that you will have some plants or trees that will benefit more than others. They, in turn could in fact, grow bigger and essentially take away all the sunlight that these little ecosystems that were on the ground were able to absorb and therefore, actually kill off entire plants in these particular areas.

So even though those little plants would benefit from having increased CO_2, —dilatorious effects would happen because they would not be able to absorb the sunlight anymore because it would not be available.

So, I think it is not just an agricultural question, I mean, it is an environmental question.

Senator **WIRTH**. This morning's newspaper carried stories about El Nino, fires in the southeast, a very dry northwest and the growth of the desertification on the area north of the Sahara.

Are any of those four phenomena, familiar to most people now in the United States, related to what we are talking about today, or are those just random changes on an otherwise relatively consistent pattern of weather behavior?

Dr. **FIROR**. It is now fairly well recognized that there is a distinctive pattern of weather in the North Pacific, in the North American continent and the North Atlantic associated with the El Nino. The El Nino is a phenomenon that is not completely understood. It occurs every few years and brings about then either a stronger or weaker version of this distinctive pattern.

I believe the things in the morning paper are all a part of the PMA pattern as it is called, the Pacific North American Atlantic pattern that follows from the El Nino that is now——

Senator **WIRTH**. El Nino is not related to the warming phenomena that we have been talking about here; is that right?

Dr. **FIROR**. Syuki, does El Nino have any thing to do with climate warming?

Dr. **MANABE**. So far, we have not come up with any convincing evidence that this warming is related to the occurrence of the El Nino. That would be a fascinating topic that we would like to study in the future. At present, we do not know.

Senator **WIRTH**. Let me ask you, and I promised you all to be out of here by noon. Let me ask you the final question.

If you were sitting down in January of 1989 with a new President of the United States and advising him on this issue, what would you tell him were the two most important things that he ought to do or she ought to do right away?

Maybe I could start with you, Dr. Leatherman, and we will just move up the table. What are the two most important things that a new President ought to know about and ought to be acting on?

Dr. **LEATHERMAN**. I assume you mean here, in terms of setting national policy or changing programs.

Senator **WIRTH**. That is what he is elected to do, I think.

Dr. **Leatherman**. In that regard, I think that the new President would have to take these projections quite seriously and start changing some of the policies with the various agencies which you have already pointed out.

Exactly how that would be orchestrated would, of course, be a long process in terms of proceedings.

I think the other thing, would be that our studies as you have seen, do show quite a large variation in terms of predictions. We do have to narrow that gap down so we get more precise.

Part of this is going to be just time. In other words, as we get more measurements through time on some of the data that you have already seen, the reliability of that data is become much better and we can narrow down our focus.

The other thing of course, as a scientist, we could always say that we need more research which I think we do. There is no question about that. From my perspective, I would say that we need to start acting now. I do not think we should delay. I think we should start pinning some new legislation to deal with some of these questions or changes in policies.

Second, I think we have to follow this issue very carefully and not let it come up to a point and let it die off. That is one of the real problems of any issue that faces the nation. Certainly you, as a Senator, because there are so many things that you have to worry about and be concerned about, that I would really hate to see this issue come to a point and then sort of decline in interest and later find ourselves in a worse predicament than we are now.

Senator **Wirth**. Make the cover of Time Magazine in one week and are forgotten the next?

Dr. **Leatherman**. Right, Senator.

Senator **Wirth**. Dr. Manabe?

Dr. **Manabe**. Yes. In my testimony I discussed this hydrological effects so maybe I could mention something along these lines. What I want to emphasize is that one of the difficulties in hydrology prediction is the fact that the wetness of soil or water availability fluctuates year to year without the effect of greenhouse gases. There is a large fluctuation.

That is why this has been very difficult to establish the effect of greenhouse gases. The other side of the coin is that in order to prepare for large-scale changes of soil wetness or water resource availability which we would expect to happen if the greenhouse gases continue to increase, one of the important things is to have very prudent water management which is prepared for fluctuation and that will go a long way to prepare for this systematic change in the soil wetness and water availability which we would expect from this large scale climate change.

Senator **Wirth**. Dr. Hansen.

Dr. **Hansen**. I think you gave us two wishes. I have one very big one, so I will put both of mine on the same one. That is, although we are very confident that there will be long term climate change, we do not understand the details well enough to give detailed advice at this time.

The reason is that the climate system is a very complicated system, and some of the key areas where we need better knowledge include ocean circulation and heat storage, ice dynamics, ground moisture, vegetation distributions and climate feedback processes especially involving cloud properties, sea ice and atmospheric water vapor.

The thing that we need in order to understand these processes better and allow us to project man's impact on climate better are global observations over a period of at least one decade. I think that these observations need to be taken during the 1990's when we expect the greenhouse effect to become apparent.

There is a very good discussion of observations that are needed in a document called "Earth System Science—A Closer View" which is about to come out. I believe that study which went on for the last few years was sponsored by several agencies including NASA, NOAA and some other agencies.

To summarize, I think that global observations of climate and how it is changing and the processes involved are the most important thing. That is where I put my wish.

Senator WIRTH. Does that relate to NASA as well? Does that have implications for the space program and our capability of getting up there to look and see what is going on, lift capability?

Dr. HANSEN. It relates to several agencies, not just to NASA. Certainly many things you can observe better from space, because you get the global view. Other things like the ocean, ocean heat storage and ocean circulation, you can get some information from space but you must also have measurements. It does relate to space measurements but also others.

Senator WIRTH. Dr. Blake.

Dr. BLAKE. It would depend on how long I was given with the President, I guess, but I would like to have this group with me and thoroughly describe the two phenomena that I am involved with; the ozone layer and the greenhouse effect.

I think it is important, first of all, that we describe more than the five or six pages in Time magazine. That was nice, but we could go a little bit deeper than that. I think that it is important that they know a very detailed discussion, have a detailed discussion about this. That is the first thing I would do.

Second of all, maybe I would take a little bit more of a hard line approach and say that if we were to—first of all, it is in the increase in these gases that we are all concerned with. If we had no increase in these trace gases we would not be here today. The atmosphere would be pretty much stable or regulating itself.

I think that the first thing that it would be in retrospect, probably, that it would be very good for us to go ahead and put strict requirements on some of these species that we have direct control over like the fluorocarbons, chloro-fluorocarbons. Some of the others, methane, it is very difficult because it is mostly biogenic. To try and cut back on the amount of rice fields and rice paddies and cows is quite difficult. But, we do have control over some.

Also, with regard to the DOE and with fossil fuel burning efficiency and moving from coal to natural gas would be a big plus there. So, maybe in a very dramatic statement I would say that whoever is involved in this type of legislation would show this very far sided viewpoint, would start to have control over two phenomena, which on a global scale and on a long timeframe, could have as much of an impact on mankind as any other thing that we have ever experienced.

Dr. **Ramanthan**. My first wish would be to request the President to slow down the rate of increase, not necessarily because of what we know but also, because of the non-zero probability that the changes may be even larger than what these models are indicating.

The second wish would be to treat this problem as a long term research problem, not something that could be fixed by an enormous amount of resources in a short period and really improve our capability of observing earth from space and also, from our present capabilities of what we can do from space is so primitive in terms of watching gradual changes.

That is one area where I think we could use really significant amount of enhanced resources.

Senator **Wirth**. Mr. Firor.

Dr. **Firor**. I guess I would have two wishes similar to Ram's. First, so I could go home and hold my head up among my fellow scientists, maintain a steady support of research in this area. Do not let it fluctuate from year to year so that we can make progress on all of the uncertainties that have been discussed here.

Perhaps more important and more direct, I would say to the President, here is a list of things you can do. If you call my friends in to testify on any one of them, they will agree in general but tell you of all the uncertainties and qualifications and it might be 10 years and it might be 30 years. Therefore, you will find it politically difficult to act on these things.

Suppressing use of coal, for example, things of that sort. Let us take that list and look at all of those things which are good to do even if we do not have climate change. Coal produces urban air pollution, it produces acid rain, it produces great scars on the land, it produces soot and so forth, as well as being the worst offender for climate change.

Let us do that, because it is good in any case. The list is quite long of those policy actions that we can take which make the country more efficient, make the country more competitive, make the country cleaner as well as slowing down this climate change whose date of arrival is, as you have heard, somewhat uncertain. But when it comes, it will be quite large.

I would try to work with the President on that list of things that we could do, we could do promptly, and which would have more than one beneficial effect for the country and the world.

Senator **Wirth**. In summary, having listened to all of you and if we then take a 10 minute period of time—we do not have as much time as we had this morning, Dr. Blake. As you know, we have about 10 minutes. So we go in and it seems to me that we say three things.

One, that it is imperative to embark over a 10-year period of time on a consistent global observation program to improve the data, for example on hydrological effects, and a variety of other items that you talked about. That is one thing that has to be done.

Second, there are very real things that we can do in terms of national energy policy that are coherent, make good economics, are beneficial in other ways and may well be beneficial to this issue of greenhouse effect.

Third, we ought to be controlling a variety of species right now which we know about, which we can control, and which we ought to get after.

It seems to me that listening to all of you, that those are the three items that come popping out right away. Did I miss some, or are those the three key items that we ought to be thinking about?

[No response.]

Senator **Wirth**. With that in mind, we will look forward to tomorrow's testimony where we will hear witnesses from the Administration and three independent agencies.

This has been a very helpful session. We greatly appreciate your input. Your testimony will be included in full in the record, and there may be other questions which the Committee or individual members may have for all of you. The record will be left open for whatever questions they may have, and further comments that you all might have in retrospect in thinking back on this.

We thank you all very much for being with us.

[Whereupon, at 12:08 p.m., the hearing recessed, to recovene Tuesday, November 10, 1987.]

GREENHOUSE EFFECT AND GLOBAL CLIMATE CHANGE

TUESDAY, NOVEMBER 10, 1987

U.S. SENATE,
COMMITTEE ON ENERGY AND NATURAL RESOURCES,
Washington, DC.

The committee met, pursuant to notice, at 9:40 a.m., in room SD-366, Dirksen Senate Office Building, Hon. Timothy E. Wirth, presiding.

OPENING STATEMENT OF HON. TIMOTHY E. WIRTH, U.S. SENATOR FROM COLORADO

Senator WIRTH. The committee will come to order. Today the committee is holding its second day of hearings on global climate change and the greenhouse effect.

Yesterday we heard from a panel of six highly-regarded scientists who told us a sobering story of global climate change being driven by the rapid buildup in the earth's atmosphere of carbon dioxide and other trace gases.

They conceded that there remain some important questions about regional and continental climate change, the hydrologic cycle, and other matters, and called for further research on these issues.

But they also pointed out that there is broad consensus within the scientific community that these gases are rapidly increasing in concentration within the atmosphere, and that these changes could drive extraordinary climate changes at a pace that defies humankind's ability to adopt.

Today we will hear from five witnesses who will tell this committee what policy options the Congress and the executive agencies should be considering to halt the buildup of these gases in the atmosphere.

There is no doubt that we need to begin weighing the steps that should be taken over the near-term, as well as over the long-term, and there is no doubt that international cooperation will be essential to meaningful action on these issues.

I look forward to hearing today's witnesses and to working with other members of the committee in pursuing the recommendations that emerge from this set of hearings.

Before beginning, let me also note that there seemed to be consensus from yesterday's distinguished panel on three steps that we ought to be taking right away.

One of those was to continue the steps begun on CFC's and trace gases. That that should be done immediately. And that we know enough to do that and do it in an aggressive and coordinated fashion.

The second was that we should be encouraging the Department of Energy in particular, to do everything that we can in terms of energy conservation, in terms of looking at alternatives to fossil fuels, that that should be done immediately. We have learned a lot from the past and we should implement what we have learned in that area.

And third, we should be conducting a coordinated, perhaps 10-year, study in the 1990s, a coordinated broad-term research program, going to a number of the questions that you have been addressing, Dr. Koomanoff.

So there was consensus in those areas. Nonfossil fuels energy, trace gases, and a much more coherent and cooperative research program among U.S. agencies both domestically and internationally.

Those were the three areas of consensus yesterday that I thought I might note at the start of this discussion. And perhaps if we have time we can ask all of you to comment on that.

Our first panel this morning is Dr. James Decker, Director of the Office of Energy Research in the Department of Energy, accompanied by Mr. Frederick Koomanoff, the Director of the Carbon Dioxide Research Division in the Department of Energy, and Mr. William Nitze, Deputy Assistant Secretary of State for Oceans and International Environmental and Scientific Affairs.

Gentlemen, thank you very much for being here. I think you are familiar with the rules of the Committee, in which your statements will be included in full in the record. We will keep the record open for 30 days for answering further questions that may come up, or additions that you may wish to add.

We would ask you to summarize your statements this morning in whatever way you think is most appropriate. And then we will proceed to questions and answers. You will be followed by a panel later this morning. And that will be the end of today's hearing, those two panels. Thank you very much for being here, Dr. Decker.

STATEMENT OF DR. JAMES F. DECKER, ACTING DIRECTOR, OFFICE OF ENERGY RESEARCH, DEPARTMENT OF ENERGY, ACCOMPANIED BY FREDERICK KOOMANOFF, DIRECTOR, CARBON DIOXIDE RESEARCH DIVISION, DEPARTMENT OF ENERGY

Dr. **Decker**. Thank you, Mr. Chairman. I am certainly pleased to have the opportunity to appear before you here today to discuss the Department of Energy's research into the greenhouse effect and global climate change.

Senator **Wirth**. Let me just note on the microphones, if you could pull them over very close to you, you have to talk right into them and then everybody in the room can certainly hear you. Thank you, Dr. Decker.

Dr. **Decker**. The possibility that man's activities may cause long-term effects on the world's climate is an important issue that we need to understand.

In fact, we know that man's activities are modifying the composition of the world's atmosphere. The question is what effect these atmospheric modifications will have on climate and human welfare.

The Department's involvement in climate change research is a consequence of our energy mission. All energy systems have byproducts that find their way into the environment, and some contribute to global climate change.

The Department conducts environmental research aimed at understanding the processes which transport these byproducts, determine——

Senator **Wirth**. I am going to ask you if you will just talk right up, I do not think the people in the back can really hear.

Dr. **Decker**. The Department conducts environmental research aimed at understanding the processes which transport these energy-related products, determine their fate in the environment, and their effect on the environment.

I will limit my remarks today to our research on the buildup of carbon dioxide in the atmosphere and the greenhouse effect.

The greenhouse effect is predicted to increase as concentrations of carbon dioxide and other trace gases, such as methane. These gases help trap heat in the earth's atmosphere by absorbing infrared radiation that would otherwise escape.

The Department is the lead agency in this field of research, providing a little over half of the Federal funding. The Department's program was organized in 1978, and it focuses primarily on carbon dioxide, which is produced in large quantities by burning fossil fuels.

In fact, carbon dioxide production is an inescapable consequence of combustion. No scrubbers or change in combustion technique can mitigate these emissions, unlike sulfur or particulates.

Carbon dioxide is expected to be the largest single contributor to the greenhouse effect. It is a very complex problem that we are dealing with; the problem of understanding the fate of carbon dioxide that is released into the atmosphere and eventually how it might bring about global and regional climate changes is extremely complicated.

Determining how much carbon dioxide is released into the atmosphere from both natural and man-made sources and how much remains in the atmosphere is a complicated problem in itself.

Some fraction of carbon dioxide that is released into the atmosphere is, of course, absorbed by the oceans, used by plants and so forth. It does not all remain in the atmosphere. In fact, only about half of the CO_2 emitted into the atmosphere remains there. However, we knew from measurements that the concentration of carbon dioxide in the atmosphere has increased about 25 percent over the last 200 years.

The second part of the problem is to predict global and regional climate changes, and that is even more difficult. Predictions of climate changes are made using large computer models that are run on supercomputers. The accuracy of the predictions depends on the completeness of the models, the accuracy of the data used in the models, and in the power of the available computers. Today's modeling of climate change is rather crude. We are not able to run controlled experiments to test these models, as we can in some other areas of science.

All models predict an increasing global temperature with increased CO_2 concentrations. However, there is a significant variation in the amount of the temperature increase that is predicted.

There are also substantial differences in predicted regional changes. For example, in a given region, some models may predict a substantial increase in precipitation, while another model will predict a substantial decrease, due to the CO_2 buildup.

We now have an effort underway to compare these global climate change models and to try to understand their differences. Our research program is aimed at obtaining the data required to provide a capability that will allow us to predict global change effects with confidence.

In 1986 we published a series of technical reports called "The State-of-the-Art Reports." These reports provide an in-depth review of the state of our scientific knowledge of the buildup of CO_2 in the atmosphere and its potential effect on the earth's climate.

Each section of these reports received extensive scientific review and they represent the best available comprehensive and authoritative reference available today. I have copies of these reports here for you. If you wish any additional copies, we would be glad to provide them.

I would like to turn now to policy implications. The greenhouse problem is truly global in nature, and the U.S., while an important contributor, is far from dominant. For example, if you look at 1950, North America contributed nearly 43 percent of the world's carbon dioxide production.

In 1984, while the total amount of CO_2 emitted into the atmosphere increased substantially, North America contributed only 25 percent. In contrast, China's contribution rose from 1.4 percent to 10 percent over in the same period.

As China continues its industrial development, its use of coal will increase substantially. China has some 75,000 to 100,000 coal mines. In 1985, China mined more coal than any other nation in the world.

Other developing nations as well can be expected to increase their use of fossil fuels, as they continue their industrial development.

Clearly a change in U.S. energy policy alone would not have a significant effect on CO_2 buildup. Any serious attempt to reduce CO_2 emissions must be done on an international basis.

The alternatives for reducing the use of fossil fuels are conservation, nuclear energy, solar where it is applicable, and perhaps fusion energy sometime in the future.

Another significant problem in some of the developing countries is deforestation to obtain land for agricultural use. Forests, of course, are significant consumers of CO_2, and their loss contributes to CO_2 buildup in the atmosphere.

Let us look at methane for just a moment, as one of the more important of the greenhouse gases. Methane, which results from natural biological processes and decay of organic material, is estimated potentially to cause up to one-third of the greenhouse effect.

Almost 40 percent of methane production is estimated to come from agriculture. It comes from growing rice and raising cattle. Much of the remaining methane production comes from naturally decaying organic material in wetlands, tundra, and other areas. Like CO_2 emissions, reduction of methane emissions will be very difficult to achieve.

Neither carbon dioxide nor methane is like CFCs, which come entirely from man-made industrial products, whose production can be more easily controlled. And, as you are aware, steps have been taken internationally to control CFC production and, in fact, to reduce their production in the future.

In my opinion, it would take an extremely compelling scientific evidence of impending disaster to convince most countries, particularly developing countries, to endure the economic penalties associated with major changes in energy policy.

We are working cooperatively with many nations to better our collective understanding of the greenhouse problem. Through this cooperative effort, we are hopeful that not only will we achieve a better understanding of the greenhouse effect, but that many nations of the world, through their participation in this research, will arrive at the same level of understanding.

In summary, the greenhouse problem is an important one. I think we should not panic at this point and make policy decisions in the United States that may be unsound. We should continue our basic applied research efforts to obtain the scientific basis required to predict global and regional climate changes accurately .

We must continue to work cooperatively with other nations in this research, so that we do develop a mutual understanding of the global change issue. If the science leads to the clear indication that emissions of CO_2 and other greenhouse gases must be curbed, it will have to be done on an international basis. Thank you.

[The prepared statement of Dr. Decker follows:]

Statement of James F. Decker

Acting Director of the Office of Energy Research

U. S. Department of Energy

before the

Committee on Energy and Natural Resources

of the

United States Senate

November 10, 1987

Mr. Chairman and Members of the Committee:

I am pleased to have the opportunity to appear before you today to discuss the Department of Energy's (DOE) research activities that relate to the greenhouse effect and global change.

The connection between energy resources, the Nation's economic security and our generally high quality of life is well recognized. Unfortunately, we do not have as good an understanding of the relationship between energy development and use and global change. Atmospheric contaminants, trace gases and waste products are examples of some of the by-products of energy use which can contribute to global change.

The Department of Energy works to help assure a stable supply of energy at a reasonable cost while also trying to improve our understanding of the effects of energy production and use on the world in which we live. DOE and its predecessors have had a long history of research related to global change. In the 1950's and 1960's it was necessary to study the transport of radionuclides to understand the distribution of radiation in the environment. Over the years this research has broadened to include studies on how a wide range of natural and energy-related materials affect and are affected by the environment. The system-oriented research approach developed for these studies is especially relevant to the emerging emphasis on global science research.

From an institutional perspective, the Department has had long experience in managing and working with large multidisciplinary programs involving laboratories, universities and other research organizations. This experience is particularly beneficial now because the environmental sciences require innovative technologies and theories to address the complex interactions that make-up global-scale phenomena. The DOE national laboratories are a major source of both research talent and instrumentation to meet the needs of the environmental sciences. The Office of Energy Research (ER), for example, has a supercomputer network that is becoming critically important for modeling global systems. Through close interaction between laboratory researchers and the external scientific community involved in global change research, laboratory-developed computer technology is now being adapted for global sciences studies.

The majority of the Department's ongoing activities directly related to global change are carried out within the Office of Energy Research. They include the Carbon Dioxide Research program managed by the Office of Basic Energy Sciences and integrated atmospheric, oceanic and terrestrial research under the Office of Health and Environmental Research.

There are other Departmental activities with missions peripherally related to global change that also contribute information to the knowledge base. They include research in ER's Basic Energy Sciences program in the Geosciences, Chemical Sciences, Biosciences and Materials Sciences. To cite just one example, one research effort underway in the Chemical Sciences is aimed at understanding key chemical reactions related to atmospheric concentrations of ozone and other trace gases. Research in the Chemical Sciences also leads to improved techniques to detect small concentrations of chemical constituents in small samples. These measurements are difficult to obtain by conventional analytical techniques. Together, these research activities are making a real contribution to the global change knowledge base. However, my statement will focus on program activities directly related to global change.

Carbon Dioxide Research

Carbon dioxide, the product of combustion, is the major gas that contributes to the greenhouse effect. The Carbon Dioxide Research program was organized in 1978 to identify possible policy options for governmental action in response to changes induced by atmospheric carbon dioxide (CO_2) in climate, agriculture and other human endeavors. The Federal government's Carbon Dioxide Research Program is coordinated by the Department of Energy. Between FY 1978 and FY 1987, U.S. Federal agencies spent $147 million on research directed toward understanding the carbon cycle, climate modeling, the response of vegetation to elevated atmospheric CO_2 and related areas. The Department of Energy accounted for 51 percent of this research investment. The National Science Foundation, National Oceanic and Atmospheric Administration and Department of Agriculture accounted for 46 percent of the research. The remaining 3 percent came from the United States Geological Survey, National Aeronautic and Space Administration and the Environmental Protection Agency.

In 1986, the Department published a series of State-of-the-Art Reports (SOA) that summarize what has been learned since the Department was given the lead to coordinate the Nation's research on changes in carbon dioxide levels. The reports cover research conducted in this country by the Department of Energy and other Federal agencies as well as the significant research carried out by the international scientific community. The four SOA reports cover the atmospheric carbon cycle, projecting the climatic effects, detecting the climatic effects, and direct effects of the CO_2 increase on vegetation. Related reports describe information required for studies of the effects of CO_2 and climate change on renewable resources and human health, and on glaciers, ice sheets and sea level. These documents provide the knowledge base about what is known, unknown and uncertain about the CO_2 issue. They also describe current data and modeling capabilities and outline potential avenues of research for reducing critical unknowns and uncertainties.

More than 70 scientists from five nations participated in the preparation of the 39 chapters contained in these volumes. In addition, each chapter and each complete SOA volume has gone through extensive peer review by the American Association for the Advancement of Science. The review involved nearly 300 international scientists.

One characteristic of the CO_2 question reemphasized by the SOA studies is the global nature of the problem. The regional trends in CO_2 emissions from global fossil fuel have been changing since 1950 due to changes in population, urbanization, industrialization and agricultural practice. For example, in 1950 when the total atmospheric CO_2 concentration was 310 parts per million (ppm), North America accounted for nearly 43 percent of the world's CO_2

emissions, Western Europe 23 percent and the centrally-planned nations of Eastern Europe 18 percent. In contrast, by 1984 when the CO_2 concentration was 330 ppm, North America contributed 25 percent of CO_2 emissions, Western Europe 15 percent, the centrally-planned Eastern European nations 26 percent, while the developing nations rose to over 15 percent. In 1950, developing countries contributed less than 6 percent. China's contribution rose from 1.4 percent in 1950 to 10 percent in 1984. These examples of rapidly changing trends in both energy use and CO_2 emissions clearly point out the need for international cooperation on research to understand the problem and determine the possible cause and effect relationships.

In addition to the publication of the SOAs there have been several important accomplishments since the Federal government received a recommendation from the National Academy of Sciences in 1977, that ". . . to reduce uncertainties and to assess the seriousness of the matter, a well-coordinated program of research that is profoundly interdisciplinary in character, and strongly international in scope, will be required." The Department of Energy has been responsive to this charge and I would like to review briefly some of the more important accomplishments and to illustrate the international aspect of our activities. There currently are about 40 international scientist-to-scientist CO_2 research projects underway. Bilateral and multilateral research has been carried on with the Soviets, the Chinese and others for many years and will continue.

Recently the detailed history of atmospheric CO_2 during the past two centuries was observed from air bubbles trapped in an ice core from Siple Station, Antarctica. These measurements, of unprecedented time resolution, were performed on cores collected by scientists from the United States, Denmark and France, with actual measurements of CO_2 change by scientists from the University of Bern, Switzerland. They have made it possible, for the first time, to trace the increase of the atmospheric CO_2 over two centuries. The measurements show that the CO_2 content of the atmosphere has increased about 25 percent, during the last two hundred years. This information is important for calculations of the rate of change of the global carbon system and for the climatic response to increasing CO_2.

In another significant accomplishment, the University of East Anglia in Britain and the University of Massachusetts have jointly developed a global temperature and precipitation database to document climate change over the last 139 years. An analysis of the records suggest that the Northern Hemisphere's average surface air temperature has warmed by about 0.3-0.7°C over the last century, although the general warming trend has not been regionally consistent. For example, north central Canada and central Asia apparently were cooler between 1920 and 1940, a period of general Northern Hemisphere warming. Despite the limitations of this database, it remains the most complete set of temperature observations for land masses of the Northern Hemisphere.

In an excellent example of formal international collaboration, the Department of Energy has concluded an agreement for a joint climate research program with the Peoples Republic of China (PRC). The agreement calls for joint research fully utilizing each country's expertise, unique facilities, model concepts and data resources. The objective is to use regional-scale data to investigate the relationships between global climate as defined by models and local climate as defined by observations. More than 30 PRC scientists and graduate students will participate in this program. Over 20 American scientists from industry, universities and the Department of Energy laboratories will be involved. The products of this collaboration will be improved data sets as well as new insights into regional climate and global change. A long-term history of regional climate is being reconstructed for China through gazettes and memos to the emperors of China, Journal notes, and a reexamination of archives of hundred year-old instrumental records. We have just received annual climate data from China for drought and floods and for temperatures from 1470-1986. This information will not only provide data for models, but clues to causes of cyclic climate changes that either could enhance or mask greenhouse effects. It should be noted that approximately 40 percent of the known world coal resource is located in the PRC and the United States.

In addition to documenting the knowns, unknowns and uncertainties about carbon dioxide, the State-of-the-Art reports also outlined avenues of research aimed at filling in the gaps in our knowledge. If we are to understand the effects of CO_2 emissions, we must learn a great deal more about the global atmosphere, the biosphere, the oceans and the cryosphere (the glaciers and ice sheets). We must understand their interactions and the effects that increases in atmospheric CO_2 and other trace gases will have on them. The effect of CO_2 concentration on climate change continues to be cited by the National Academy of Sciences (NAS) as a prime example of a global and multidisciplinary problem that must be addressed in a global change program. It should be recognized that for the past 10 years the Department of Energy has been conducting research on this problem of global change.

The CO_2 research program, with a budget request of $14.0 million for FY 1988, is made up of four areas of study: energy systems and carbon cycle research, climate systems, ecological and agricultural systems and resource analysis. From energy systems and carbon cycle research we are trying to estimate future atmospheric CO_2 levels. To be able to make such estimates, we must increase our fundamental knowledge of the exchange of carbon among natural reservoirs, for instance, the atmosphere, oceans, and terrestrial biosphere. Our specific objectives are to quantify those exchanges and to estimate the changes in atmospheric CO_2 concentrations from past to future anthropogenic (i.e., human) activities. Research in this area focuses on fossil fuel CO_2 emissions, atmospheric observations of CO_2, fluxes between ocean and biosphere, and modeling of the global carbon cycle related to energy technologies.

Research on climate systems is directed toward reducing uncertainties about CO_2-induced regional and seasonal patterns of climate change and understanding the interactions among the atmosphere, the oceans and the cryosphere. Specific objectives are to estimate the rate and magnitude of a regional CO_2-induced climate change and to determine when such a change has occurred.

Since climate models differ widely in their predictions on a regional scale, our research also aims to understand why the model predictions vary so significantly.

Through research on agricultural and ecological systems we are trying to determine the response of crop and natural systems, such as forests, to increased concentration of atmospheric CO_2 and changes in climate. Specific objectives are to determine the effect of CO_2 concentration on the yield of major crops and the fundamental effects of long-term elevated CO_2 exposure on plant physiology and growth. Research is also underway to evaluate the response of natural ecological systems to CO_2 in terms of productivity and altered plant and animal composition.

Resource analysis is aimed at understanding how the direct effects of CO_2 (e.g., changes in climate and vegetation) affect natural resources, such as water and forests, and human welfare. The goal of current research is to provide integrated quantitative analyses of the effects of CO_2-induced climate change on key resources on a regional basis. This analysis includes the pros and cons of various adaptive or corrective measures. Primary areas of study are water resources, agriculture, shoreline, health and natural ecology including forestry and fisheries.

Environmental Research

Now let me turn to the Environmental Research activities of the Office of Energy Research. In the next decade we clearly need to develop a better global scale understanding of natural and induced changes on the total ecosystem called earth. There are many factors already identified that influence global change. They include climate, the composition of the stratosphere, shifting ocean currents, changes in marine productivity, chemical contamination of food chains, irreversible soil deterioration, and desertification among others. Multidisciplinary research will be required to improve our understanding of how these factors affect each other and contribute to global change. The DOE environmental program is beginning to develop such interactive research. Let me take a moment to describe some of the ongoing process-oriented research that is necessary in any integrated program to understand and predict global change.

The environmental research program, managed by ER's Office of Health and Environmental Research, with a budget request of $36.3 million for FY 1988, is aimed at understanding the processes which transport energy-related products and determine their fate in the environment. For example, we need to be able to predict how the by-products of a given energy technology released at a given location are transformed and transported to other locations. Attention is focused on the pathways and mechanisms by which energy-related substances move through the environment ultimately to come in contact with human populations, and on the ways that the environment itself may be affected by such substances. The program encompasses areas of atmospheric and oceanographic sciences and terrestrial ecology. This information, in conjunction with our knowledge of the human health effects of energy technology by-products, allows a full global assessment of the impact of any proposed energy strategy.

The atmospheric research program is concerned with the chemistry and physics of emissions from energy production and use, their interaction with other trace gases and particles, their wind driven movement and dispersion and the processes which cleanse them from the atmosphere and deposit them on the ground. A large part of the atmospheric program supports the National Acid Precipitation Assessment Program (NAPAP) through studies of the atmospheric chemistry in cloud/precipitation systems during rainstorms. NAPAP was established by the Acid Precipitation Act of 1980 (Title VII of the Energy Security Act, P.L. 96-294). NAPAP is a 10 year interagency research effort that is coordinated by a committee of senior representatives including representatives from the Departments of Energy, Agriculture and Interior, NOAA and the EPA. Atmospheric research conducted under NAPAP is reviewed yearly for progress in our understanding of acid rain effects on the environment.

We also are working to develop predictive models of air currents over mountains and valleys. Techniques developed under this research program were used for determining distribution of the Chernobyl fallout. The pattern of radioactive releases from the Chernobyl nuclear reactor accident that began in April 1986 has been analyzed to provide estimates of possible future health effects in exposed populations. Appropriate environmental transport models were used to integrate data from affected countries in order to estimate present and future distributions of radiation doses to pertinent population groups. Based on the most recent risk projection methodology, estimates of possible increases in cancer mortality and in genetic effects, among others, have been derived from these dose projections for population groups in the USSR, the United States, and other regions in the Northern Hemisphere. The findings are contained in the Department of Energy's Report entitled, "Health and Environmental Consequences of the Chernobyl Nuclear Power Plant Accident" (DOE/ER-0332 issued in June 1987).

The oceanographic program grew out of a 1957 National Academy of Sciences report which called for a fundamental understanding of oceanographic processes that govern the movement of radionuclides in the ocean. This initial program has provided the tools and insights for understanding the transport and fate of other energy-derived contaminants. The current research program is focused on the coastal areas of the United States. Boundary areas along the coastal zone where land and fresh water interact with the open ocean are extremely productive areas biologically which are exposed to damage from pollutants and the influence of open ocean dynamics. In this program, researchers are learning how material from the land and continental shelf moves into ocean basin circulation as well as how the open ocean influences shelf dynamics.

A new European marine study called ECOMARGE is being patterned after the DOE coastal margins program. ECOMARGE is aimed at understanding dynamics along the eastern part of the Atlantic Ocean and their influence on the global ocean. Dr. Pierre Biscaye from Columbia University, a major grantee in the DOE oceanographic program, is serving as a consultant to ECOMARGE which is primarily funded by France and the European Economic Community. DOE will collaborate with this European program through personnel, data and equipment exchanges.

Modern terrestrial ecology owes many of its origins to DOE's predecessor, the Atomic Energy Commission. For example, the use of radiotracers in ecology, stemming initially from concern over the transport and fate of fission isotopes in the environment, provided some of the fundamental concepts, tools, and resources to help move ecology from a largely descriptive to an experimental science. The initial basic research on isotope effects in natural systems provided the basis for the paleotemperature studies which are so important in present day climate/CO_2 studies, as well as in what has come to be known as stable isotope ecology. The ability to reveal ecological relationships has expanded to the examination of entire ecosystems -- both biotic and physical components. Understanding this complex network requires detailed knowledge of the way biological elements are changed by soil, air and water, and by surface properties of cells and mineral particles. The current program encompasses activities ranging from the molecular scale to large-scale landscapes.

This multidisciplinary terrestrial research is conducted on landscape units and watersheds ranging from the Arctic to the tropics (Puerto Rico) but is primarily carried out on DOE land surrounding DOE-owned installations. These land areas have been designated as National Environmental Research Parks and represent major ecosystems including arid, semiarid, humid and wetland regions. The holistic approach of studying the total ecosystem has resulted in an understanding of carbon, sulfur, calcium and nitrogen cycling in different ecosystems. This research approach, initiated in the late 1960's, has provided an important base of information for emerging environmental problems, e.g., for understanding acidic deposition in forested ecosystems and carbon cycling in relation to the CO_2 program. Finding unifying principles that apply across wide ranging spatial and temporal scales is a challenge of both intellectual and practical significance, and requires intensive application of the most advanced engineering and computational facilities. Research plans are now being developed to address these challenges of spatial and temporal scaling using landscape and regional approaches.

Terrestrial ecology is undergoing a major revolution in the way the science is conducted and in theories on complex multiscaled interactions. Ecologists are not only reaching out into other fields for advanced instruments, and techniques to adapt them for ecological research, but they are actively developing new devices and theories as needs are identified for better understanding of global scale phenomena. The Department of Energy's national laboratories are a major source of advanced instrument development for biomedical, military and energy-related uses. Through close interaction between these researchers and environmental scientists, this technology is now being adapted for the study of ecology. Also, scientists supported by other agencies are embarking on new directions to investigate the terrestrial environment. In April 1987, the Department sponsored a conference aimed at bringing together interested researchers from the DOE laboratories, other Federal agencies, universities and industry to exchange information and ideas on the advances in techniques and theories taking place in ecology.

Coordination

Coordination of these varied research activities is an important facet of DOE's programs. The Department continues to believe that coordination with other Federal agencies and international organizations involved in the research is essential not only to avoid duplication but also to encourage the scientist-to-scientist interactions that lead to advances in our knowledge base. Coordination takes place through a variety of formal and informal mechanisms: workshops, task forces, distribution of publications, conferences, one-on-one conversations and formal international agreements. Let me take a moment to highlight a few of our coordination activities.

In April of this year, the President's Science Advisor, Dr. William R. Graham, created the Committee on Earth Sciences (CES) within the structure of the Federal Coordinating Council on Science, Engineering and Technology (FCCSET). Dr. Graham took this action in recognition of the potential for mankind to contribute to significant changes in the global Earth system. This Committee will coordinate Federal research efforts on earth sciences. The CES will take full advantage of existing policy formulation channels, agency plans and operations and the existing relationships between those institutions and the broader scientific community. By working through the existing program and policy channels, which are operating effectively, CES will ensure that the Federal government meets its responsibilities to respond to the increasingly complex issues of a changing global environment.

As the Acting Director of Energy Research, I am a member of this new FCCSET Committee on Earth Sciences as well as the Policy Board of the National Climate Program. The Department is also represented on the Interagency Remote Sensing Committee which coordinates remote sensing needs and activities of the various agencies. The Department also is an active participant in the U.S. Global Ocean Science Program chaired by the National Science Foundation. The participants currently are working to develop a five-year program plan for a global marine program. DOE looks forward to participating in this collaborative multi-agency research program.

In addition, the Department supports many of the National Academy of Sciences committees of the National Research Council, from the Polar Research Board to the Committees on Oceans, Chemistry, Climate and Solar Terrestrial. Through these committees, an effective dialogue is established with other government agencies and with the science community.

The Department's current involvement with the International Geosphere-Biosphere Program (IGBP) takes place through the NAS Global Change Committee which, in turn, is working with the Special Committee for the Geosphere-Biosphere Program established by the United Nations' International Commission on Scientific Unions. The Department continues to support the concept of a broad IGBP that recognizes and encompasses all complementary research activities. We look forward to the development of initiatives that are unique to and require the support of the IGBP. We continue to believe that research must be focused on developing the knowledge base needed to aid in decisionmaking. It is not a question of limiting what should be included in the IGBP, but rather providing the needed knowledge base and the well formulated plans required to answer the specific questions facing society. The Department is particularly interested in global phenomena where effects can be traced to energy activities. Past performance assures that DOE has the competence and commitment to address energy and environmental problems on a local, regional and global scale; and the Department welcomes the challenges of an IGBP.

The Department and its predecessors have a continuing record of commitment to long-term scientific research programs. We look forward to participating in the International Geosphere-Biosphere Program and to contributing to the scientific knowledge that will be used by decisionmakers around the world to address the global change issues that affect us all.

That concludes my statement. I will be happy to answer your questions.

Senator WIRTH. Thank you.
Mr. Nitze.

STATEMENT OF WILLIAM A. NITZE, DEPUTY ASSISTANT SECRETARY OF STATE FOR ENVIRONMENT, HEALTH, AND NATURAL RESOURCES, DEPARTMENT OF STATE

Mr. NITZE. Thank you, Mr. Chairman. The State Department very much appreciates the opportunity to testify on this issue today.

We regard global climate change as one of the most serious international environmental problems with which we have to deal. And a problem with very serious long-term implications.

As Dr. Decker has pointed out, however, we need to do a great deal more research and identify precisely what those implications may be.

We are already doing a great deal internationally, in cooperation with other countries, to learn more about this problem. The United States is a very active member in the World Climate Program, and particularly in the data and applications aspects of that program. We have developed a climate computer program, and are helping fund that program.

We have a number of satellite observation and other activities which are making a major contribution to the worldwide effort to study the problem and learn more about the impact of greenhouse gases on world climate, both currently and more importantly out into the future years.

We also have a number of bilateral agreements with other countries covering research on global climate issues. Those countries include the Soviet Union, the People's Republic of China, Canada, India, Brazil, and France.

It is of particular note that in the recently-concluded U.S.-USSR agreement concerning cooperation in the peaceful uses of outer space, there is an item 11 which stipulates that the two countries will coordinate their activities in the study of global change of the natural environment. And I believe that some 30 projects have been identified as prospects for joint United States-Soviet research in this area.

The United States is also fortunate to have a number of semigovernmental or nongovernmental organizations that are committing significant resources to the study of this problem.

They range from institutions like NCAR out in Boulder, with which I know you are very familiar, to a number of NGOs, some of which will be testifying before you here this morning.

So I think as a nation we have a great deal to offer in terms of research on this problem and helping others understand its implications.

However, we at the State Department feel that it is important that there be a stronger intergovernmental mechanism bringing together the governments of the world in order to look at the problem, see where we are in terms of data and analysis, and begin to identify impacts, and at an appropriate time consider policy options.

I stress at an appropriate time, because although I think we have a pretty clear idea that there will be a certain amount of global warming in the future, the magnitude of that problem, its timing and its regional and local distribution are still very uncertain, as Mr. Decker has pointed out.

The United States has been active in trying to create such an intergovernmental mechanism. We took the initiative at the WMO and UNEP meetings last summer to propose it at a recent meeting of the organizing committee for the next World Climate Conference, scheduled for late 1989 or early 1990.

We put forward some more specific ideas as to how it might work. And we are hopeful that next summer, at the WMO general meeting, that a mechanism will be adopted.

I think it is very important that not only the developed countries but also the key developing countries be represented in this mechanism, because, as Mr. Decker has pointed out, it is in a sense the developing countries that face the most difficult policy issues.

They have to build up an energy infrastructure to support moving from a relatively low level of economic activity to a much higher one, and hopefully they have to find a way of doing it which will not substantially contribute to the global climate problem.

Within the U.S. Government itself, we do have a fairly developed mechanism for coordinating our efforts on global climate change. The key coordinating mechanism is the recently-established Committee on Earth Sciences, which is run by the President's Office of Science and Technology Policy out of the White House.

And then of course we have the National Climate Program Policy Board, established under the National Climate Act, on which all of the key agencies involved in the problem, including the State Department, are represented.

I would just like to repeat in closing that we do take this problem very seriously. We think it deserves a lot of very serious work. And we look forward to working with you and other Members of Congress on it. Thank you.

[The prepared statement of Mr. Nitze follows:]

STATEMENT OF
WILLIAM A. NITZE
DEPUTY ASSISTANT SECRETARY OF STATE
FOR ENVIRONMENT, HEALTH AND NATURAL RESOURCES
BEFORE THE
COMMITTEE ON ENERGY AND NATURAL RESOURCES
UNITED STATES SENATE

NOVEMBER 10, 1987

Mr. Chairman and Members of the Committee:

Thank you for the invitation to testify on global climate change, a subject of great importance to current and future generations. I am glad to comment on international cooperative efforts to address this complex issue.

Global cooperation is required to better understand and predict natural and man-induced climate change, particularly in light of mounting evidence that the chemical composition of the Earth's atmosphere is being changed by man's activities and that this is likely to lead to an unprecedented global warming within the next few decades.

The principal forum for international coordination of climate-related activities is the World Climate Program. Formed in 1979, the World Climate Program is administered by the World Meteorological Organization (WMO), with active participation by the United Nations Environment Program (UNEP), the International Oceanographic Commission (IOC), and the International Council of Scientific Unions (ICSU).

Like the U.S. National Climate Program, the World Climate Program addresses not only diagnosis of the current state of the climate system and the factors having an influence on climate, but also exploration of the predictability of climate on time scales of months to decades. In recent years, increased emphasis has been placed on assessment of the consequences of the ongoing change of the composition of the atmosphere, its potential of changing the climate, and associated impacts on natural and managed ecosystems.

The World Climate Program is divided into four components: Data and Applications, which are administered by WMO; Research, which is jointly implemented by ICSU and WMO; and Impact Studies, implemented by UNEP. The U.S. National Climate Program works closely with WMO on the Data and Applications elements. For example, the United States formulated the concept of and contributes to CLICOM, a Climate Computer System to assist nations in better organizing and using climate data and information. The United States participates actively in many international observational projects within the World Climate Research Program, for example the Tropical Ocean Global Atmosphere Project, known as TOGA; the World Ocean Circulation Experiment; the International Satellite Cloud Climatology Project; and the International Satellite Land Surface Climatology Project.

UNEP activities under the World Climate Impacts Studies Program have focused largely on developing countries, promoting consideration of climate factors in national policy decisions on alternatives for development. The Program has concentrated on reducing risks and adverse climatic impacts on food systems and agriculture, and on developing methodologies for climate impact assessment. UNEP has recognized, appropriately, that we need to know much more about the regional impacts of greenhouse-gas-induced global warming.

Numerous international meetings have been held and are planned to exchange information on various aspects of climate change, such as the nongovernmental meetings in Villach, Austria in October 1985 organized by UNEP, ICSU and WMO, and this week in Bellagio, Italy, organized by the Beijer Institute of Sweden. We believe, however, that it is now time for governments to take a hard look together at what we know and what we need to know about potential climate change and its impacts.

With this in mind, at last summer's meetings of the WMO Congress and UNEP Governing Council, the United States proposed, and the WMO and UNEP governing bodies adopted, resolutions calling for the two organizations to cooperate to establish an intergovernmental mechanism to assess the state of knowledge about the magnitude, timing and potential impact of climate change. The UNEP Governing Council also called for UNEP's Executive Director to report to the next Council meeting on the "full range of possible responses by governments and international organizations to anticipated climate change, including possibilities for reducing the rate of change."

The objective of the intergovernmental mechanism we proposed would be to see that there is an effective interface between the science and policymakers. It would not undertake scientific research itself or duplicate existing scientific information exchange mechanisms. It would be an intergovernmental forum under the auspices of WMO and UNEP within the existing World Climate Program, not a new organization.

In addition to the multilateral effort under the World Climate Program, the United States is actively engaged in bilateral climate programs. For example, we have carried out significant cooperative research with the Soviet Union since 1972 under our bilateral Environmental Agreement. Under that agreement, the U.S. and the Soviet Union signed a protocol just two weeks ago to undertake more than thirty joint climate research and global change projects next year, increasing present cooperation in studies of human effects on climate. Coordination of activities in the study of global changes of the natural environment is also an element of the U.S.-Soviet space agreement signed last April.

More broadly, the International Council of Scientific Unions (ICSU) is planning an International Geosphere-Biosphere Program (IGBP), a major, long-term multi-disciplinary approach to assessing all aspects of global change, including climate change. The IGBP will seek to gain an understanding of the interactive physical, chemical and biological processes that regulate the total Earth system, the unique environment that it provides for life, the changes that are occurring in this system, and the manner in which they are influenced by human actions. IGBP will emphasize interactive processes that are not addressed by other existing programs -- it will integrate and supplement rather than duplicate existing activities, with emphasis on the need for an adequate global data and information system.

Many other specific programs relate to various aspects of climate change, such as efforts to preserve tropical forests and to understand the role of the oceans in the carbon cycle. But I believe this outline is sufficient to indicate the extent of the web of international efforts which exist to further the effort to understand, predict and respond to potential climate change.

There is much to be done in international cooperation with regard to global climate change. As I indicated, we particularly believe it important to see that there is an appropriate interface between the science and policy. We have begun a process to create the necessary structure to address this need. On the science side, adequate international cooperative programs exist or are planned, and deserve U.S. Government support to ensure a unified and continuing commitment to global research and monitoring. Change -- natural and man-induced -- is inevitable. We need the best possible understanding of that process of change to provide a foundation for national and international policymaking.

Senator **Wirth**. Thank you very much, Mr. Nitze. Thank you, Dr. Decker.

Mr. Koomanoff, do you have anything you might like to add?

Mr. **Koomanoff**. Just a few things, sir. First, I think your 10-year concept is excellent and we have been moving forward during the past year and a half in the same direction.

Let me give two examples, if I may. One of the things that we found from our State-of-the-Art Reports, which were produced by 80 scientists from five nations of the world and reviewed by over 300 scientists from 26 nations of the world under the auspices of the American Association for the Advancement of Science, was that at regional and continental levels, our models, our GCMs, these excellent tools that have been created by the science community, differ significantly in their output. We then decided that we should try to help the science community to find out why they differ.

We enlisted the assistance of Dr. Robert Cess from SUNY at Stonybrook, who, working with Dr. Potter at Lawrence Livermore, just this past June had a meeting in Washington between the GCM modelers from the People's Republic of China, the U.K., and Canada, and all of the major modelers in the United States from NCAR, Warren Washington, from Oregon State University, Larry Gates and Mike Schlesinger, and Dr. Manabe from the Geophysical Fluid Dynamics Lab in Princeton, and Dr. Hanson from the Goddard Institute for Space Studies.

They came up with the whole concept of how to go forward, step by step, to intercompare the models to see why they differ: Is it the way we treat the physics? Is it the data we use? Or what?——

The comparison is to be undertaken in the hopes that we will not have a beauty contest to judge which model is the best one, but to find out why these models differ so that we can take corrective action.

When the German modeler heard about the intercomparison, he wrote and asked if he could also be kept informed and said he would like to participate. Also, just a few weeks ago, when the Soviet delegation was here, we talked to them about certain runs that they could do on their GCM which would, again, help in this intercomparison.

Secondly, approximately three weeks ago at Wood's Hole, each of the major government agencies involved—EPA, DOE, NSF, U.S. Forestry Department, U.S. Department of Agriculture—held a very excellent workshop attended by about 75 to 100 of the leading scientists in the ecological modeling and plant physiology areas.

Because CO_2 is a fertilizer for plants, we must model an ecological system that we can understand as a system that is affected by CO_2 both positively and with regard to climate, temperature, and precipitation change, and possibly negatively, so that both of the these impacts can be taken into consideration.

This meeting was extremely successful. Even as I talk to you today, members of all of these government agencies are meeting to see how we can cooperatively move forward. So yes, we are working in these directions to try to get our government agencies working together and to get the international science community working together.

We brought along a copy of our program summary for 1987, which indicates every one of the research projects that we have supported, who is involved in each as a principal investigator, the objective of each, and, for the first time, we have indicated the project results to date, which I think you might find very interesting.

Senator **Wirth**. Thank you very much. We might see if we have agreement, Dr. Decker, from you on the research that has gone on that shows there is a likely warming. Is that right?

Dr. **Decker**. Yes.

Senator **Wirth**. And that carbon dioxide contributes significantly to that. Is that right?

Dr. **Decker**. That is correct.

Senator **Wirth**. And that part of the carbon dioxide comes from natural, or agricultural processes, and some comes from fossil fuels. Correct?

Dr. **Decker**. Yes.

Senator **Wirth**. And that if there is such a warming, which is likely, where there is some disagreement about how rapid that is going to occur and its intensity, but it is certainly going to be there. Correct?

Dr. **Decker**. Yes.

Senator **Wirth**. Is it not logical then that we have to begin to think what the consequences of that might be?

Dr. **Decker**. Surely.

Senator **Wirth**. And that we probably ought to begin now to take preventive action. That even if were to assume, for example, the low end of the best estimates, and if we are wrong, the consequences could be very, very significant. Correct?

Dr. **Decker**. Sure.

Senator **Wirth**. What efforts are underway at the Department of Energy to transmit this understanding of the potential warming, the significant contribution of fossil fuels to CO_2, gets transmitted to the energy policy people at the Department of Energy, and how is that done?

Dr. **Decker**. I think certainly the Department of Energy's policy people are well aware of the greenhouse effect, and are considering it.

It has not perhaps been incorporated in our policies to a large extent at this point because of the fairly large uncertainties that exist in the predictions and the——

Senator **Wirth**. Did we not just establish the fact that there is broad agreement? I mean, there is some uncertainty about the extent and the speed with which it is going to occur.

What I infer from your testimony as it was prepared and from your statement today is that there is a tendency, as I read it, to perhaps hide a little bit behind the uncertainty rather than to come out and say, hey, we have some very significant problems here and we ought to change the policies of the Department of Energy accordingly.

Do you think that that is a fair conclusion?

Dr. **Decker**. Well, I think that we do not want to rush into some policy decisions too early.

Senator WIRTH. Well, one policy implication that is pretty obvious is that we ought to be really encouraging conservation?

Dr. DECKER. I would agree that certainly conservation is important.

Senator WIRTH. If that is the case, if the policy implication is that we ought to be encouraging conservation, for example, then why would it be rational to, say, lower mile-per-hour standards for new automobiles?

How would that be a logical conclusion from the research that you have done? Or why would it be a logical conclusion to dramatically cut funding for solar energy? Or why would it be a logical conclusion to dramatically cut funding for other kinds of conservation measures?

Do you see what I am saying? It seems to me that there is a discrepancy between the conclusions that come out of your statements, and the research, and the policy decisions of the Department of Energy. How am I wrong in that?

Dr. DECKER. First of all, conservation clearly is important. A lot of conservation decisions, of course, are made in the marketplace.

And the fact of the matter is, with energy prices being relatively low, conservation has not been on the minds of the public nearly as much as it was a number of years ago.

Senator WIRTH. Is not one of the roles of the administration to point out what this problem is and to advocate conservation.

Has there been an advocacy of conservation from the Department of Energy?

Dr. DECKER. Yes, I would say it has not been a major push.

Senator WIRTH. What do you think has happened to the conservation budget in the last seven years?

Dr. DECKER. Well, I am not responsible for the conservation programs, so I do not know the details.

Senator WIRTH. If the research is pretty clear in one area, and if the trends are pretty clear in one area, therefore there ought to be some effort made to take that research and build that into policy.

We established that that would be a logical thing to do. We agreed upon the trend. The need to take that information and build it into policy was a second thing that we agreed upon.

Is that happening? I think the answer to that appears to me to be a pretty resounding no.

Dr. DECKER. My perception of what has happened to the budgets in solar and conservation and in some of the other energy programs is that, first of all, the Department has gotten out of large, expensive demonstration projects.

The research, I do not think, has been affected in a major way, but we have gotten away from these large projects.

Senator WIRTH. What do you mean, large projects?

Dr. DECKER. More demonstration projects.

Senator WIRTH. We are talking about research, for a minute. Let us talk about research.

Dr. DECKER. The research budgets, I do not think, have suffered substantially.

Senator WIRTH. Have you looked, for example, at the research budget for solar energy?

Dr. **Decker**. Yes, but I think the total budget includes demonstration projects, or has over the last number of years.

Senator **Wirth**. The point that I make, and I know you are not responsible for this, but it seems to me that there is a very significant discrepancy between where we know the trends are going and what action is being pursued at the Department of Energy.

And that is not your obligation. It is probably our obligation to see if we can button this up in some more coherent fashion, and to take some sense of urgency that comes out of the findings of the research, and make sure that that does get reflected in the policy areas. And I want to come back to that in a minute.

Let me ask you a couple of very specific items. Knowing what we know now about trends, does that argue that it makes sense for us to be, say, opening up the North Slope of Alaska for energy production, production of fossil fuels?

Or would we be better off emphasizing conservation, which, according to witnesses from this Administration, could get us just as much if not more energy than the production coming out of ANWR?

Dr. **Decker**. Well, again, certainly conservation is important.

I think that energy policy involves a number of factors, one of which is that we have an abundant supply of energy available in this country at a reasonable cost. I think that opening up ANWR is part of an attempt to ensure that part of our energy policy.

Senator **Wirth**. It is a difficult question for you, I know, and that is not your responsibility either. But it just seems to me that the gap between what we know in terms of the research and what we are doing is even wider when you get down to specifics.

Let me ask you another question. There was some discussion earlier about the importance of forests in terms of absorbing carbon dioxide. If that is the case, does it make sense for us to be encouraging, either domestically or internationally, the destruction of rainforests?

Dr. **Decker**. I would think that we should not be encouraging it.

Senator **Wirth**. Therefore we should be taking what we know and discouraging, for example, the clear cutting of vast areas in the Tongass, or we should be discouraging policies in the World Bank to be cutting down rain forests in Central America, or we should be working as much as possible with the Australian Government or the Indonesian Government to maintain the rain forests there. Should we not?

Dr. **Decker**. That sounds sensible to me.

Senator **Wirth**. It seems to me that that is pretty logical.

So therefore, the hell-bent for leather efforts to cut down the Tongass would seem to run directly in the face of everything that we have learned about the impact and the relationship of forests to carbon dioxide and global warming. Right?

Dr. **Decker**. From the perspective of this problem, that is certainly true.

Senator **Wirth**. Secretary Nitze mentioned that we should have a stronger intergovernmental mechanism, and I want to come back to that if I can, Mr. Nitze.

Should we have a stronger mechanism domestically, a stronger interagency mechanism to coordinate the efforts that exist, from the Department of Energy and the Department of the Interior, for example, and the Department of Transportation? All of which, and others, have a responsibility in this area.

Dr. DECKER. I think that our inter-agency coordination is pretty good at the present time.

Senator WIRTH. Were you all consulted, knowing what you know about carbon dioxide, were you all consulted when Secretary Dole made the decision about automobile standards?

Dr. DECKER. The Department may have been consulted. I was not.

Senator WIRTH. Well, what kind of an inter-agency mechanism do we have then for coordinating these steps?

Dr. DECKER. Well, certainly in the research area, we have, I think, good coordination.

There is a new entity that has been formed, as Mr. Nitze mentioned, the Committee on Earth Sciences, which is under the Office of Science and Technology Policy.

Senator WIRTH. So from your perspective, Dr. Decker, there is no need for any better, stronger mechanism for coordinating these efforts?

I am just picking up on what Mr. Nitze was suggesting in terms of an international, an intergovernmental mechanism. Should we have a stronger interagency mechanism at home?

Mr. KOOMANOFF. We also have the National Climate Program Office, sir, which is very, very much involved in the area of climate and climate change, of course, and will very soon be putting out its recommended 5-year research program.

Senator WIRTH. Do you think the National Climate Program has talked to the Secretary of Agriculture about the Tongass?

Mr. KOOMANOFF. No. I doubt that they have. I can only address the questions of the scientific research. On some of these other questions, I am sorry, I cannot.

Senator WIRTH. I understand. The point that I am making, it just seems to me it is very clear that we know that there are these trends out there, right? There is broad agreement on what is happening.

Mr. KOOMANOFF. Reforestation is an excellent idea, wherever it is done. The Chinese are doing it.

Senator WIRTH. If we are going to be encouraging reforestation, we should not be encouraging deforestation. Should we?

Mr. KOOMANOFF. No. And the science community, again, but——

Senator WIRTH. Mr. Nitze, talk a little bit more about the need for a stronger intergovernmental mechanism. What does that mean in terms of policies that we ought to be pursuing in the Congress? What could we do that would be helpful to encourage that?

Mr. NITZE. Frankly speaking, Mr. Chairman, one of the reasons why the government should be very closely involved in following ongoing research and shaping conclusions with respect to impacts and policy options is that ultimately, in the long term, governments are going to have to make some of the key policy choices.

And you have a number of important countries, the United States, the Soviet Union, and China, to name three, that have a very important fossil fuel resource base, particularly coal.

And in our case, we have obviously developed a very significant infrastructure to exploit that natural resource base. And as Dr. Decker has mentioned, the Chinese are in the process of building up their own infrastructure, and the Soviet Union has done likewise and would like to extend it into eastern Siberia.

And it is very important that countries in that position and some of the developing countries, like Brazil and Indonesia, be actively involved in the process. And as information becomes available, and as different options are developed, then those governments will feel part of the process and will probably be better disposed to make sensible policy choices in the future.

That is why we are not only strongly supporting a mechanism organized under the auspices of the WMO, but strongly supporting developing country involvement in that mechanism.

Because these are not easy choices. I mean, there are some real economic costs involved in doing some of the things that might, on the surface, appear desirable to do. And therefore it is important we try and organize any transition here in a way that has the minimum negative economic impact. And that is especially true for some of these developing countries.

Senator WIRTH. It seems to me that if we are going to embark on a process of serious negotiation and serious discussions with, say, the People's Republic or the Soviet Union or developing countries, we have to come to the table with a pretty strong position ourselves.

And that it is very difficult. I would think it would be very difficult for us to go to the Indonesian government, or to go to the Brazilian government, or to go to the Costa Rican government, and ask them to make difficult economic choices, when we have been, from what I gather, unwilling to make those difficult economic choices ourselves.

It is good for you guys to do that, but we are not going to do it. Now, am I naive about how these negotiations work? How would we be viewed if we go to the Indonesians and say, do not cut down the forest there, while we are doing it in our backyard?

Do not burn fossil fuels, we say to the Chinese, but we are going in just the opposite direction. Do you see what I mean?

Mr. NITZE. Yes. I am not fully knowledgable on the subject. But I think the United States is in a better posture than perhaps you suggest on some of those issues.

I believe that actually forests in this country are continuing to recover from a low level in the early part of this century. We do have, I think, quite good forest practices with our major timber companies.

We have an extensive national park system. We have set aside many additional lands. We have been very supportive of efforts through multilateral lending institutions, and through the new International Tropical Timber Organization, to avoid or change development projects which are destructive of tropical rainforests.

In fact, a person from my office is going down to a meeting of the ITTO right now, and we will be supporting research projects to figure out how to encourage development in tropical countries without cutting the trees down.

So I think we are pointed in the right direction in a number of these areas. We do have a very major research program going on, as you have heard from Dr. Decker, on innovative coal technologies, which will burn coal more efficiently, as well as have fewer emissions of sulfur and nitrogen.

We have substantially improved the efficiency of our automobile fleet. There are a lot of good things that have happened in this country.

I do not think we have to be ashamed about our record. And I think we have a lot to offer in terms of technology and policy ideas to other countries. So I think we can take a positive leadership role.

Senator WIRTH. In the Department of Energy statement, it is stated that the United States produces, I think the number is about 25 percent of the total CO_2 emissions, and the Soviet Union, or the centrally-planned economies, account for 26 percent.

One conclusion that you could draw from these statistics is that the U.S. and the USSR have to be the leaders in reducing global emissions of CO_2. And that if we together could embark upon an aggressive program, that would be better than either of us doing it alone.

Mr. NITZE. Yes. I think that you are talking about probably the two largest energy countries. We are the largest energy consumer, and they probably have overall if not the largest, one of the largest energy resource bases.

I think it is very important that we participate and take a leadership role in any international effort. But again, it is going to take a lot of work to figure out exactly how we proceed.

The Soviet Union in a sense is making a contribution by its natural gas production, which it uses domestically and sells to Europe. So there are a variety of different options we have to look at.

But yes, I think we and the Chinese have a natural leadership role in this area.

Senator WIRTH. What kind of efforts are underway to work with the Soviets? Are you familiar with that?

Mr. NITZE. Yes. The Soviets are very interested in global climate change, and as I mentioned there is a specific item in the recently-concluded outer space agreement which refers to joint research. And we will be pursuing that research.

Senator WIRTH. Specifically, what kind of joint effort is going on, or what kind of joint research has been proposed, or what kind of joint colloquia are planned?

Mr. NITZE. I will have to turn to Fred Koomanoff. But I believe a lot of it has to do with satellite monitoring of atmospheric dynamics. Fred?

Mr. KOOMANOFF. Of course, at the 30th anniversary of Sputnik, they did talk about that greatly. But we also have a protocol between the Soviet Union and the EPA, which is basically Protocol VIII.

And just two weeks ago, Academician Badeko and the leading members of the Academy of Science in the Soviet Union were over here. We had meetings last November in Leningrad where we talked about the CO_2 issue. Each group presented papers. We are now designing a major meeting, which will be held in approximately a year and a half, between Soviet and American scientists. We will be publishing that proceeding as a book for major distribution.

Dr. Badeko and Yuri Israel, who are the equivalent of the Administrators of EPA and NOAA, have just edited a book of papers on CO_2 climate change in the Soviet Union by different authors, and we are working with them to get it translated so that we will be able to help distribute the concepts that the Soviets are considering. So we are working very, very closely on a scientist-to-scientist basis.

We have also just signed a protocol with the People's Republic of China, involving two of the institutes of the Chinese Academy of Sciences, the Institute of Atmospheric Physics and the Institute of Geography.

Now, the Institute of Geography literally has a room bigger than this one with Chinese climatic records and weather records going back, in some cases, up to 1,000 years, of the Fu Districts in China, as they call them.

We have just gotten our first hard disk from them, which had data going back to 1470, a proxy type of data, and then to 1770 of instrumented records, which was the first instrumented records that were kept in China, by the Jesuits mainly. It is pretty interesting data, all the way up to today.

So we are getting some old historical data from the Chinese by region. We then expect to run our GCM's and compare the CO_2 levels, because you cannot verify it directly. But this is working back with historical data to do it.

Also, the Chinese have not had large-scale computers, therefore, some of their mathematical solutions to problems are even better than ours.

We are working with them now to improve some of our routines in our GCM's, which we think may actually speed them up maybe 25 percent, which is very, very much when you think that one run of a GCM, a general circulation model, on a Cray computer, takes about 100 hours of computer time. It is very expensive and very time-consuming.

And thirdly, deserfication in China is very, very great. We are working with them there in trying to study the relationships of between climate and the cause of deserfication, as well as other human activities.

And fourthly, China has 38 percent of all the rice paddies in the world and about 10 million biodigesters, which use waste material to generate methane for energy. It also generates CO_2.

And for the first time, Dr. Rasmussen from the Oregon Graduate Center has gone to China and has actually taken measurements of methane over different types of rice paddies.

He found radical differences, depending on how the rice is grown, in how much methane is emitted. Now we are going to be able to have better estimates. The Chinese will continue collecting this data and we will also get samples of it.

It is an initial, very limited investment. The Chinese Science Group does the work, and we share the scientific data.

And fifthly, on the TOGA program, which is the Tropical Ocean Global Atmosphere program, an international program under the WMO: The Chinese have a route through the Indian Ocean. We have put one of our doctorate candidate students on one of the Chinese boats and we have been measuring the partial pressure of CO_2 in the ocean, a very important area of the world on which we do not have data.

This shows how international cooperation works. On the TOGA expedition, we took it at one time of the year. About five months later, a Russian ship with an American scientist on it went almost the same route. We found radical differences in the two sets of data that we had never anticipated.

This is where international science cooperation, working together, is going to give us the information so that we can really make some positive and, I think, important decisions down the line.

But until we really understand regional climate change, how best to adapt to it, we will not know. And, of course, conservation, safe fission, solar energy, photovoltaic energy where it could be utilized, and fusion, maybe in the future, are all things that we should pursue.

Senator WIRTH. Dr. Decker, if you had the opportunity to sit down and talk to the chairman of the Appropriations Committee up here, or to talk to the Speaker of the House and say, this is what we ought to be doing, what would you ask him for, in terms of ability to re-organize, research funding, and so on?

What are the most important things that are needed that you currently do not have?

Dr. DECKER. Well, I am not sure that I would recommend anything in the way of different organization of programs. I think that the programs are working pretty effectively now under the present organizations.

With regard to budget, of course the budget for research on the greenhouse effect is constrained, as it is for all R&D programs given the present budget difficulties with which we all live.

You know, we certainly could benefit if we had more computer time to run models and this sort of thing. I mean, we always have more that we can do.

Senator WIRTH. Mr. Koomanoff, how would you answer that question? Or what would you say to the Speaker or to the leader?

Mr. KOOMANOFF. As Dr. Decker said, sir, in the science community, you always want more money. I would say that we need to really firm up a 10-year program plan, specify what our milestones should be, and try to reach those milestones.

This is very difficult when you are doing science, because you do not know about potential results. When you sometimes ask scientists for deliverables or reports, they get very upset, because they really want to do their science.

And you cannot blame them, because that is really where the great talent is, but, at the same time, this contract comes out.

I think we have to find out why these models differ, and be able to produce sensible information. I think we also have to create world databases on resources for use when we talk about things like agriculture and forestry.

In the United States we have very good data. When you go out to some other countries of the world, the data is not really that good as yet. We are just starting to get some of the better data because of global observation systems, Landsat data, for example, and data from the French.

So one of the things we need is some good databases. Another is to get a much greater increased, multi-disciplinary approach to some of these problems, in which we get the physicists, the economists, and the political scientists to sit down from day one.

And then the last thing I think that I would recommend is that we find a way to create a dialogue, right now, between and among the science community, the policy analysts, and the political people, like yourself, because one of the things that is important is that we learn together—not that the science goes for five years and then you get a half hour report from someone and then have to make a decision on it.

We really need to find a way of creating a dialogue, a continuous dialogue, so that, as new scientific information and new approaches come in, you can learn and be part of the process.

Now, how to do that, I do not know. But that is one thing that I would recommend very strongly.

Senator WIRTH. This is very consistent, Mr. Koomanoff, with yesterday's testimony.

We have been talking about a 10-year program, multi-disciplinary, multi-agency, international effort, and then the job is one of taking that material and translating it into policy, which we have been talking about a little bit today in response to my earlier questions.

Does that need a legislative framework, do you think? Are we better off embarking upon that if we set a program for the 1990s that says, this is what we are going to do and to embark upon this kind of a broad research program? Should we mandate the kind of cooperation that you are talking about?

Mr. KOOMANOFF. No, sir, I do not think you can force cooperation. It has to come over time and it has to grow. Five years ago, if someone had talked about having inter-comparison between models, forget it. Three years ago, forget it. The time is now. So there is a time when it is feasible.

Second, I do not feel that you can legislate scientific findings.

Senator WIRTH. Nobody is suggesting legislating scientific findings.

Mr. KOOMANOFF. I am sorry. That is the inference I got.

Senator WIRTH. How do you embark upon, how do we make sure that this sort of thing happens?

I have been in this institution now for 13 years, and you see items make the cover of Time magazine, and everybody talks about it, and three months later it is gone.

Energy is a perfect example. Eight or 10 years ago we were deeply embroiled and concerned about energy policy. And in this day and age, even to get people to talk about it is very difficult. It is coming back a little bit, but it is very hard to do. So what I am concerned about is, do we need to embark upon a 10-year program, how do we launch it and make sure we do everything we can to see that it happens and does not fall off the edge of the table like a lot of other things do?

Mr. **Koomanoff**. Well, I do know that we and the National Climate Program Office, especially the policy board, are trying to work towards this, very, very much so.

I know we in the Department of Energy will, in January or February of this year, hopefully, be publishing our recommended 10-year program of what we feel has to be done and when. Ideas of that nature.

I think this new committee that has been created, the Committee on Earth Sciences, is excellent. I think one of the key things in any of these areas is that there be a clear objective, because a lot of times the objectives and goals become so fuzzy that no one can move forward.

Senator **Wirth**. Mr. Nitze?

Mr. **Nitze**. I was just noting the point. I do think that the one committee that I have participated in, which is the National Climate Program Policy Board, is a very good forum for coordinating within the Executive branch, at least, what we are doing on this issue. And I think we are making some progress.

The idea of developing an intergovernmental mechanism and actually tabling some proposals with WMO really arose in that committee. And I think that committee is a good vehicle for our participation in a number of international efforts leading up to the next World Climate Conference. So I am quite optimistic, at least, on my side.

Senator **Wirth**. It sounds to me, from listening to you all, that we are doing a better job, perhaps, of coordinating and pursuing our efforts internationally than we may be domestically.

That comes through loud and clear from this morning, and maybe it is only the result of my own point of view in questioning. That might be the case, Dr. Decker.

It just seems to me, from everything we heard yesterday and what we have heard this morning, and from my own experience in this area, that we have to do a much better job of coordinating our domestic efforts.

And if that is the case in terms of energy policy I suspect that may be the case in the area of this research as well. And maybe there is something that we can do.

We would like to get back to you on this, if we might, Dr. Decker and Mr. Koomanoff. I was over at the National Academy last night talking to a variety of people there who are very interested in becoming involved in this.

Senator Johnston, the Chairman of the Committee, is very interested in this. And it seems to me that we have a responsibility to probe this further and see what we might do to encourage the kind of advocacy, the kind of coordination, and the kind of targeted efforts that are needed.

We can't dictate results. We know a lot better than that, I can assure you. But perhaps Congress can be of assistance in making sure that we are pursuing the issue as best we can.

Can I ask you one final question, if I might? And that relates to coal and nuclear. As I listened yesterday, and as I listened to you this morning, I come away, and correct me if this is the wrong impression. I come away saying that if we were to start de novo, or if we were to take on a rational research program, that research program would probably put a much greater emphasis on nuclear than we have done in the past.

And what we ought to be doing is embarking upon a very ambitious research program to redesign our efforts in the area of nuclear power, to focus on making them a lot safer, making them potentially a lot more benign, that that is long-term going to be a lot more productive for us than pursuing a program of coal and fossil fuel.

Now, that is counter-political, you might say. Right? If you read in this morning's paper about many different organizations getting together and saying that we have to shut down all the nuclear power plants, or whatever it was.

I just read the first two lines of the story. There is a kind of nuclear measles in the country or whatever. Everybody wants to stay away from it or quarantine anything that relates to nuclear.

But if you look seriously at all of this, we ought to be a lot more aggressive in the area of nuclear and we ought to be doing a lot less in the area of coal and coal-burning. Now, is that a logical conclusion that comes out of this?

Is this consistent with what you know and see, Mr. Nitze?

Mr. **Nitze**. The direct answer to your question, Mr. Chairman, is yes. But I have to add that the State Department does not really make the call on this issue.

Senator **Wirth**. I understand. You have not been here that long, and you are getting really good at this.

Mr. **Nitze**. But I think from what I have heard that even the environmental community itself is rethinking that issue, and you might wish to ask some of the witnesses on your program later this morning.

I firmly believe personally that nuclear has a very important role to play in this country's energy mix, and I very much regret what has happened to the nuclear industry and the whole regulatory process.

If there was something we could do about that, I think it would be positive. But I think DOE probably would be better speaking to the issue.

Dr. **Decker**. Basically, I agree with what you said. It is a shame that nuclear power has undergone the problems that it has and is not being used by the country to the extent that it should be used.

At the same time, given the public perception problems with nuclear energy and being concerned about the security of energy supplies, it is understandable, I think, why people have been pushed toward developing coal technologies, because we do have that as an abundant resource in this country.

Senator **Wirth**. Mr. Koomanoff?

Mr. **Koomanoff**. Again, if I may, let me use China as an example. The Chinese plan to build two nuclear plants between now and the year 2000.

Working with the World Bank, they have said that they will triple their gross national product. To triple that gross national product means that they will have to use coal, because they just do not have the capital to build nuclear plants.

That means, in my estimation and from the calculations that I have made, that, over the next 25 years, if the Chinese economy grows the way it looks like it will grow—and I have only been to China twice, but I have been amazed at just the difference in those two visits, and I think it will grow that way, then the Chinese are going to use an awful lot of coal. They account for 10 percent of the coal-use CO_2 emissions today, and in making future estimates, you cannot have a one-to-one transformation, so you cannot just say they will account for 30 percent of the emissions, when they triple their gross national product. Rather, they will be a major contributor to them.

You are going to find this in other countries of the world, too. I think this is what Dr. Decker was trying to point out, the international aspect of this thing. But it is basically the Northern Hemisphere where the emissions are coming from.

I think that, more and more, anything that increases energy efficiency is just as good as energy conservation. It is basically the same thing. So I think the clean coal technology, that will let us use coal with less pollutants, as well as more efficient energy systems, has to be on the plus side.

By the way, sir, between 1980 and 1984, the per capita emissions of CO_2 in the United States were reduced by about 10 percent, which was a result of energy efficiency that had taken time to get into the system. But then, as of that point, it started being lost, because of the cheap oil or gasoline.

Senator WIRTH. Do I gather from your comments that clean coal technology reduces the emissions of carbon?

Mr. KOOMANOFF. No. Sulphur dioxide. CO_2 is a product of combustion. SO_2, of course, is a pollutant.

Senator WIRTH. I did not want the record to go away with the suggestion that if we burned coal more cleanly, we are going to make a contribution to slowing down the amount of carbon dioxide in the atmosphere.

Mr. KOOMANOFF. No. If at the same time you have energy efficiency.

Senator WIRTH. Of course.

Mr. KOOMANOFF. That is the key. Energy efficiency.

Senator WIRTH. So it is really an efficiency, not a clean——

Mr. KOOMANOFF. Exactly. But Dr. Decker mentioned before that, even with the clean coal technology, there was going to be energy efficiency.

I was just picking that up again, so that you would get the advantage of hearing both things at one time.

Senator WIRTH. Are there further comments that you might like to make before we move onto the next panel?

[No response.]

Senator WIRTH. We are very pleased to have you here. We look forward to working with you, particularly as we try to figure out what we can do that would be most productive and constructive.

And as you muse on this and have some thoughts, we look forward to hearing from you as well. We will leave the record open in a formal fashion, and we are always available on a more informal fashion. I thank you very much.

Our second panel this morning includes three distinguished witnesses, Dr. Gordon MacDonald from the MITRE Corporation in McLean, Virginia, Mr. Gus Speth, President of the World Resources Institute in Washington, D.C., and certainly no stranger to the deliberation of this Committee, and Dr. George Hidy, from the Electric Power Research Institute in Palo Alto, California.

Gentlemen, thank you all very much for being here. We appreciate your patience this morning in waiting for your turn on the panel. You are familiar with the rules of the Committee.

We will include your statements in full in the record, and we will leave the record open for the next 30 days for you to add material that you think would be helpful to the Committee and for us to include questions that we might have of you.

Dr. MacDonald, why don't you begin, and summarize your testimony in whatever way you think would be most helpful?

STATEMENT OF DR. GORDON J. MacDONALD, VICE PRESIDENT AND CHIEF SCIENTIST, THE MITRE CORP., McLEAN, VA

Dr. MacDonald. Thank you, Mr. Chairman. It is a very great privilege to be here today. The subject that you are addressing, I think, is one of the key issues that we will face over the coming decades.

As you look back through history, there are abundant examples of mass migrations, fallen empires, plagues, all brought about by climate change. Clearly today the societies are less vulnerable, except those societies that live at the margin.

The unfortunate people of equatorial Africa have seen the devastation that can be brought about by prolonged drought. For industrialized societies, the cost of climate change will also be great, because there will be a need to develop alternative crops, new water supply resources, perhaps even building levees to protect coastal areas, compensating for prolonged periods of crop failure and relocating populations.

These are all high-cost. And they result from a variety of effects. For example, the fires in the Southeast of the past week contribute to the carbon dioxide burden of the atmosphere.

They destroy wood and the fires produce carbon dioxide in the process, and open up soil for erosion, which will result and further carbon being released to the atmosphere. This is just an example of what will become a more frequent event in the future, if indeed the climate changes, of which I think the scientific community has now reached a consensus on, do come about.

In sort of developing the thesis that climate change is of very great importance, I would like to touch on three points. First, the scientific advances which yesterday were covered in an excellent fashion. So I will just touch on one additional point.

Second, changes that are taking place in how the world is using energy. And then concentrate primarily on those steps that this country can take to slow down potential changes in climate.

Among the advances in science have come, one, the recognition that gases other than carbon dioxide contribute to the greenhouse effect. Second, that over the past 100 years there has been a miserable warming trend.

Third, and I think quite importantly, an analysis of gases trapped in glaciers gives us an indication of what the atmosphere was like many thousands of years ago.

And what that information tells us is that as the glaciers advanced and retreated, there were very major changes in the carbon dioxide content of the atmosphere, and that there is a close tie between the composition of the atmosphere, something that we have thought about and speculated on.

But I think the comparison of past compositions of the atmosphere with the actual climatic change show, without any question, that cooling was associated with very low carbon dioxide content warming periods.

Both the most recent one, beginning about 10,000 to 12,000 years ago, and another warming period that extended between 120,000 and about 135,000 years ago, were characterized by significantly higher carbon dioxide concentrations in the atmosphere than existed during the glacial periods.

Yet these concentrations of carbon dioxide, during the interglacial periods, the warmer periods, are well below the levels we have now reached in the atmosphere today. And indicate that we have already put into the bank major warming trends for the climates of the future.

Now, let me turn to the trends and energy usage over the past, let us say, 40 years. First, in looking at these trends, we have to recognize that not all fuels have equal effects on the composition of the atmosphere.

The production of energy through the use of nuclear or solar, of course, does not add carbon dioxide to the atmosphere.

The production of natural gas produces about 40 to 50 percent less carbon dioxide than the use of oil to produce the same energy. And 70 percent to 90 percent less carbon dioxide than the use of coal to produce the same amount of delivered thermal energy.

This means that in addition to the amount of the fossil fuels that are used, it is the mix of fuels that is important in determining how much carbon dioxide gets into the atmosphere.

And there the trends are discouraging. Between 1950 and the late 1970's, the world's dependency on coal decreased consistently. But beginning in the late 1970's and continuing on today, the dependency of the world on coal has once again begun to increase, so that the fraction of the energy derived from fossil fuel that comes from coal is increasing on a worldwide basis.

This is even accentuated to a much greater extent in the United States. In 1973, about 18 percent of the energy delivered by fossil fuels came from coal. Today about 26 percent of that energy comes from coal.

This turns over in terms of the amount of carbon delivered to the atmosphere of going from 24 percent associated with coal in 1973 to 33 percent, or one-third, of all the carbon that gets into the atmosphere from the U.S. use of fossil fuels, comes from coal.

So that we can see that there are two trends——one worldwide, one within the United States——of the world turning to its most abundant fossil fuel, that is coal, and at the same time we recognize that coal produces more carbon, carbon dioxide, places it into the atmosphere when it is burned, than do the other fossil fuels, natural gas and oil.

So we have a situation that even as energy usage worldwide is not increasing at the same rate as it was in the 1960's and 1970's, the amount of carbon dioxide placed into the atmosphere continues to increase at approximately the same rate as the mix of fuels shifts from oil, predominantly oil, to a greater fraction coming from coal.

Now, what actions should be taken? The United States produces approximately 26 percent of the carbon dioxide that enters into the atmosphere. One-quarter of the world's total.

So it is not alone, by any means. So that clearly, efforts to ameliorate the effects of climate change will require cooperation in the international regime.

But the United States needs to play a leadership role in establishing a position in which it is clear to the world that we are concerned about nuclear power. A position that we established in the case of the chlorofluorocarbons, the CFCs, and the world took to our position. And as a result, we have moved towards a valuable international convention in that particular area.

I think the same thing is needed within the United States. And to do this I think that there are two major areas that need attention. And a number of minor areas.

The major areas relate to a point that you addressed in the last question of your previous panel, and that is, we need to re-establish nuclear energy as a viable alternate energy source.

Second, we need to move ahead with a better pricing scheme so that the cost to society of the disposal of carbon dioxide into the atmosphere is reflected in the price of the fuel itself.

And that is, attempt to bring in the free market system to give a preference first to conservation, so you do not use as much energy. Second, to nuclear or solar, energies that do not use or produce carbon dioxide. And thirdly, to provide a competitive, a further competitive advantage of natural gas compared to oil, or natural gas and oil compared to coal.

First, with respect to nuclear, I think the steps that need to be taken are steps that we all recognize are important. The issue of high-level waste disposal needs to be resolved expeditiously. As someone who has worked in geology, and as my technical area of expertise I believe this can be done.

Second, the safety concerns need to be addressed. Unit standardization, a variety of new technologies can be brought in. And I think safety can be very much enhanced. We must recall that the reactors on-stream today were reactors developed with 1950's technology. In 1980 or 1990 we can do a much better job in ensuring safety.

Third, the regulatory chaos that currently exists in the nuclear industry must be righted. We cannot continue to proceed in which the utilities are uncertain of the future, and the government regulatory apparatus is in such bad shape.

And fourth, I think the Federal Government does need to continue and enhance its support of research for safer nuclear energy. And included in that would be going towards smaller unit reactors.

Let me now turn to the question of waste disposal of carbon dioxide. The climate effects of carbon dioxide are certainly not reflected in the current pricing of fossil energy.

The end-user has no economic incentive to choose the fuel that would result in lower climatic effects. In standard economic terminology, the relative external costs of altering climate are not borne by the fuels.

The policy of neglecting climate change as an external cost stands in contrast to the requirement that users of nuclear fuel pay the Federal Government a fee designed to cover the cost of waste disposal.

In the case of fossil fuels, the waste receptacle is the global atmosphere. But there is no fee for disposing of the principal industrial waste. A well-designed charge system to attempt to right these economic difficulties would attempt to reflect the true cost to society in the fuels.

Because of the complexity of the problem, I think even today this would be difficult to do in any precise way that would satisfy economic theoreticians. However, I do believe that for illustrative purposes, one can consider a charge of, let us say, a penny for each kilogram of carbon put into the atmosphere.

This would result in a charge on natural gas of about 14 cents per thousand cubic feet, about $1.20 for a barrel of oil, and about $5 for a short ton of coal. This charge would then recognize that there are differences between these fuels in the damage that they do to the atmosphere, and enhancing the potential for long-term climate change.

Now, the issue of the concept of charging for the disposal of a waste, carbon dioxide, a common property in the atmosphere, is certainly not new. In fact, when I was a member of the Council of Environmentally Quality in 1971, we proposed such a charge for sulfur dioxide in coal.

The Congress at that time failed to act on that proposal. But since then, and even before that, there has developed a rich literature in the economic world commending the internalization of waste disposal costs.

Now, there are a number of additional steps. The major steps that I would advocate are, as I say, the attempts to revive the nuclear industry. Second, to internalize the cost of burning carbon in the price of the fuel.

But there are a number of other steps that need to be taken. Recently we have heard a great deal about the use of methanol as a substitute for gasoline to power automobiles, particularly in regions now heavily affected by air pollution.

Methanol, whether it is derived from natural gas or coal, is a synthetic fuel. And as a result requires energy in its production, as well as releasing carbon dioxide in its final burning.

As an alternative of methanol, natural gas would provide an energy source for automobiles that would be helpful in terms of urban air pollution, and would exact a much lower cost in terms of loading the atmosphere with carbon than would methanol.

Here we come to a particular point, which again was raised in the earlier panels, how can one part of government, in this case the mobile division of EPA, be advocating methanol as an alternative fuel, while other parts of government are concerned with carbon dioxide?

I think there is a way of dealing with these problems. Inherent within the environmental impact statement procedure is a requirement to look at all significant effects on the environment. Climate can be one of those significant effects.

The requirement that the environmental impact statement contain a discussion of climate, I think, would further raise the issue. I think it is clear that that requirement was built into the initial Environmental Policy Act. But I think it could be applied, or should be required today.

You raise the issue of the Tongass forest. There is a climatic impact, as you point out, of cutting in the Tongass forest.

I am not certain, but I would venture the guess that whatever impact statement the Forest Service has prepared on cutting has not contained a discussion of the longer term climatic effects of cutting in the Tongass forest.

The Federal Government, and in particular the Department of Energy, has sponsored research into the physical and biological aspects of climatic change. Far less attention has been paid to the analysis of the energy policy issue that this hearing is attempting to get at.

A scientific understanding, even if imperfect, is an essential prerequisite for policy action. The analytical community has not yet focused on means by which the scientific findings can be translated into public policy.

In part, this lack of interest reflects a lack of Federal interest and financial support. And I hope that this committee will continue not only to support scientific research on climate change, but will also require the Department of Energy to analyze the policy options that flow from the science discovery.

Now, there are further points that I would say, as noted in the earlier panel discussion. Clean coal technology has received great emphasis by the Department of Energy. There has been less attention to further research on advanced nuclear energy fission.

Further, there are potential resources of natural gas that at one time in the 1970s received Federal attention, but no longer do.

The unconventional sources of natural gas, such as the Western tight sands, the shales of the Eastern coast, the geopressurized gas resources of the Gulf Coast. All take new value in the light that natural gas is indeed a more beneficial fossil fuel than is coal.

In summary, then, I would say that the energy policy of the United States needs to take into account the long-term climate effects. To do this, nuclear energy must be placed on a sound basis with the resolution of the waste disposal and safety problems.

The economic advantages of coal, and to a lesser extent oil, that stem from the free dumping of waste into the atmosphere, must be removed, so that the fossil fuels begin to pay for their waste disposal cost to society.

Energy conservation slows climate change and should be encouraged. Again, the user charges that I discussed promote conservation in an economically efficient way. Synthetic fuels are economically wasteful and hasten climate change. Their use should be discouraged.

The actions of the Federal Government should be subjected to rigorous analysis for implications to climate change through NEPA's environmental impact statement procedure.

The Federal Government should increase supportive research into the physical and biological aspects of climate change, and should develop a broad-ranging program to support research on policy options available to deal with potential climate change.

Future research emphasis on fossil fuels should shift from coal to unconventional sources of natural gas, including geopressurized gas. I believe that the wise management of energy is essential if we are to prosper.

In order to succeed in this task, we need to begin to address the questions relating climate change to energy policy. I hope this committee will continue to exert the leadership in treating these complex problems that is exhibited in calling attention to it by holding these hearings. Thank you, Mr. Chairman.

[The prepared statement of Dr. MacDonald follows:]

RELATIONSHIP BETWEEN CURRENT ENERGY TECHNOLOGIES AND THE GREENHOUSE EFFECT AND GLOBAL WARMING

Statement by Gordon J. MacDonald[*]
Before the Committee on Energy and Natural Resources
United States Senate
November 10, 1987

Thank you Mr. Chairman. It is a high privilege to appear before you and to have the opportunity to comment on an issue whose time has come. Over history, climate has played a decisive role in determining the infrastructure of the world's societies. Today, man is changing climate in unprecedented ways and with a rapidity far exceeding natural changes. The degree to which the climate of the future differs from that of the past three hundred years will depend on choices made now as to what energy sources will be employed and how this energy is to be used. The actions of your Committee, with its large responsibilities for energy, will play a central role in guiding the United States and the world in a period of fundamental change. Albert Einstein once said: "I never think of the future. It comes soon enough." For climate change, soon is now. Careful thought is needed if we are to be prepared to act wisely as the rate of change increases.

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My central thesis is that climate exerts the dominant influence on how societies structure their underlying institutions. Weather and climate, which is a thirty-year average of weather, influence a region's energy use, growth of plants and animals, means of transportation, water supplies, natural areas, pattern of habitation--in brief, its infrastructure. Descriptors of climate, temperature, precipitation and moisture, determine whether vegetation is forest, prairie, tundra or desert; a central tenet of plant ecology is that climates make the plant. Temperature and availability of moisture also determine the ease with which societies can adapt to natural stresses. The frequency of such extreme events as tornadoes, hurricanes, floods, blizzards and killer hot spells affects the habitability of a region and determines the investment required to moderate economic, physical and social stresses created by climate. The entire physical and economic infrastructure of a region is an adaptation to prevailing climate, an adaptation developed over centuries, but accelerated in the last three hundred years with the explosion of industrial-agricultural societies. During the past three centuries of instrumented observation of climate, nature has been kind; climate has remained stable since the deep changes of the Little Ice Age that devastated 17th century Europe with famine and plague, and similar wide swings in earlier times.

Historical migrations and displacements of people and societies have accompanied past changes in climate. For example, the prevalence of extreme arid conditions over much of the near East and Central Asia in the centuries around 1200 B.C. led to turmoil and disruptions in the advanced societies bordering the eastern Mediterranean. At roughly 1500 B.C., the Aryan people poured out of Iran to settle in northwest India. By 1200 B.C., the Mycenean empire of southern Greece collapsed as the Dorian tribes moved in from the north, driven from their lands by food shortages. Drought forced the Hittites to abandon their homelands on the Anatolian plateau, and Egypt was threatened by bands of Hittites and Syrians leaving their stricken lands. Again, around 1500 B.C., the ancient Chinese Yang-shao and Lung-shan cultures were overwhelmed by horse-riding peoples from central Asia who had been expelled by drought.

Most of the great shifts in population were caused by agricultural failures due to increased frequency of droughts. But shifts in temperature alone can produce severe effects, as my ancestors came to know. In the golden age of the 12th and 13th centuries, cereal crops flourished in the Highlands of Scotland. Deterioration of climate by A.D. 1300 had wiped out much of the wheat, and the Scots turned to raising sheep. By the end of the 14th century, the north of Scotland was engulfed in clan warfare as food became scarcer. In the decade of the 1430s, tree bark was the only available substitute for grain in bread. In the general turmoil, King James I of Scotland was murdered on the edge of the Highlands in 1436; no place north of Edinburgh Castle could be considered safe for the King, and thus Edinburgh became the capital of Scotland.

Prolonged periods of warmer temperatures were accompanied by a rise in sea level. During the warmer centuries of Roman times, the sea level rose one to two feet, submerging earlier harbor installations in the Mediterranean. The transgression of the sea between A.D. 250 and 275 caused flooding along the coasts of Holland and Flanders, forcing major shifts in the coastal population. Along the English and French coasts, lives were lost as the higher sea levels brought increased tidal flooding.

In past times, societies were much more vulnerable to climate change than present industrialized societies. Even today, people living at the margin can be overwhelmed by climatic shifts, as has been tragically demonstrated in equatorial Africa. For industrialized societies, climate shifts will extract a cost in developing alternative crops and water resources, building levees to protect coastal areas, compensating for prolonged periods of crop failure, and relocating populations--as well as attempting to provide stability--in those marginal regions of the world. These costs will be high, even though they cannot be precisely evaluated today.

In developing my thesis, I will discuss three topics:

- three scientific developments of the last decade that definitively link climate change with energy use;
- changes in U.S. and worldwide energy use over the last decade which intensify the greenhouse effect; and
- steps that the U.S. and the world should be taking to ameliorate climate change and societal disruption.

Your Committee's major responsibilities are with the third topic. I will primarily attempt to address these issues, but I recognize that much remains to be done in policy analysis if we are to move with confidence.

Scientific Advances in Understanding Climate Change

The recognition that societal activities can alter climate is only 50 years old; a British scientist, G. Callendar, first raised the subject in 1938. Intensive study of climate change began years later with the accelerated interest in environmental quality that ultimately led to the National Environmental Policy Act of 1969 and the flood of environmental legislation in the early 1970s.

The last decade has seen three profound changes in understanding climate change:

- Carbon dioxide (CO_2), a product of fossil fuel combustion, is not the sole contributor to the greenhouse effect. Methane, nitrous oxide (NO_x) and ozone(O_3)--all products of energy use--will contribute to climate warming. Nitrous oxide is a direct product of the burning of coal. Ozone and methane result from the production of carbon monoxide (CO)--a gas which alters atmospheric chemistry in a way that increases methane and ozone concentrations. In anticipating climatic change, gases other than carbon dioxide will contribute approximately as much warming.

- The earth's present-day surface temperature is about 0.5° Celsius warmer (0.9° Fahrenheit) than it was in 1890; the warming at higher latitudes (60°N) is 2 to 4°C (about 3.8 to 7.6°F). Detection of the warming trend was impossible before the present time because of the diverse character of the available data. Tens of millions of temperature observations have been taken under widely differing conditions with disparate instruments over land and ocean. Modern computer technology has made analysis of these myriad data possible. The unequivocal result of the analysis is that an overall warming has occurred during the past century. Interpretation of surface data is strengthened by measurements of subsurface temperatures in the frozen Arctic, where ancient temperature regimes are preserved. The warming of the last century has not gone smoothly, but despite the erratic course of the earth's surface temperature, it is clearly escalating. The amount of warming observed relates directly to the increased carbon dioxide content of the atmosphere. On the average, the global temperature and fossil fuel emissions have increased together.

Measurements of trapped air from the Greenland and Antarctic ice sheets demonstrate that the carbon dioxide concentration of the atmosphere during the glacial periods beginning 12,000 and 135,000 years ago was at least 30% lower than the concentration 300 years ago, before the industrial age. Concentrations of carbon dioxide during the interglacial period 115,000 to 135,000 years ago were comparable to those of the preindustrial atmosphere. The detailed concordance between past atmospheric carbon dioxide concentrations and glacial epochs provides irrefutable evidence for a fundamental link between greenhouse gases and global climate. Observation of air trapped in ice over the past two hundred years establishes the links between increased carbon dioxide in the atmosphere and warmer surface temperatures; both now march in step with heightened burning of fossil fuels.

Recent Patterns of Use of Carbon-Based Fuels

The exponential growth in atmospheric carbon dioxide concentration correlates with the release of carbon dioxide by the burning of coal, oil, natural gas and wood. Between 1958, when detailed observations of atmospheric carbon dioxide were first made, and the present, the concentration of CO_2 has increased from 315 parts per million to 350 parts per million. The amount of carbon added to the atmosphere by the burning of fossil fuels has followed a closely similar exponential trend.

The amount of carbon dioxide which is added to the atmosphere by using fossil fuels depends on the quantity of fuel burned and on the mix of fuels. The amount of carbon delivered to the atmosphere per unit of heat energy produced depends on the composition of the fuel. The high hydrogen-to-carbon ratio in natural gas leads to a lower carbon dioxide emission per unit of energy delivered than other fossil fuels, as is illustrated in Table 1.

Table 1

Carbon Dioxide Emissions from Direct Combustion of Various Fuels

Fuel	CO_2 Emission Rate (kg C/10^9J)	Ratio Relative to Methane
Methane	13.5	1
Ethane	15.5	1.15
Propane	16.3	1.21
Butane	16.8	1.24
Gasoline	18.9	1.40
Diesel oil	19.7	1.46
No. 6 fuel oil	20.0	1.48
Bituminous coal	23.8	1.73
Subbituminous coal	25.3	1.87

When "synthetic" fuels are used, the amount of carbon dioxide released to the atmosphere is higher than that of fossil fuels. Energy used in the production of synthetic liquid or gaseous fuels, such as methanol from coal, oil from shale, or gas from coal is itself a source of CO_2. The total amount of CO_2 emitted through the use of synthetic fuels includes the quantity released during their production; the conversion costs add to the atmospheric burden of carbon dioxide. Finally, use of nuclear, hydropower and solar energy does not add to the greenhouse burden.

Worldwide, the patterns of energy use have changed over the years. These changes are shown in Table 2, which lists total carbon emitted, and the percentage contribution of each fuel type to energy

Table 2

CO_2 Emissions from World Use of Fossil Fuels

Year	Fossil Energy (Quadrillion, 10^{15}, Btu)	Total CO_2 (Gt of C)*	Percent Energy/CO_2 Due to: Gas	Oil	Coal
1950	71	1.62	12/7	29/26	59/67
1960	115	2.54	17/11	35/33	48/56
1970	198	4.04	22/15	46/45	32/40
1980	261	5.13	23/16	47/47	30/37
1984	263	5.20	24/17	44/44	32/40

*Billions of metric tons of carbon.

production and CO_2 release. The dominance of coal in 1950 was a continuation of the pattern established early in the industrial revolution. From 1950 through the mid-1970s, the relative contribution of coal to the world's energy economy declined. This trend underwent a major shift in the early 1980s as a rapid rise in the price of petroleum products prompted a return to coal, increasing coal's relative contribution to energy and to the atmospheric CO_2 burden. The increased worldwide reliance on coal implies that even if world energy consumption decreases in the future, carbon dioxide emissions may still increase.

In the United States, the relative contribution of coal to the energy economy has continued to grow steadily over the past 15 years (see Table 3). In 1985, as a result of expanded nuclear power and effective energy conservation, the United States used 6% less energy derived from carbon-based fuels than in 1973. However, because a higher fraction of that energy was delivered by the burning of coal, emissions of carbon dioxide decreased by only 3%, while total world production of carbon dioxide increased.

Table 3

CO_2 Emissions from United States Use of Fossil Fuels

Year	Fossil Energy (Quadrillion, 10^{15}, Btu)	Total CO_2 (Gt of C)*	Percent Energy/CO_2 Due to: Gas	Oil	Coal
1973	70.3	1.38	32/23	50/53	18/24
1975	65.3	1.29	31/22	50/53	19/25
1980	70.0	1.39	29/21	49/51	22/28
1985	66.3	1.34	27/19	47/48	26/33

*Billions of metric tons of carbon.

If current worldwide fuel use trends continue, the carbon dioxide concentration can be expected to rise from the present value of 350 parts per million to about 450 parts per million in the year 2030. Such an increase of carbon dioxide would, by itself, raise the global average temperature one degree Celsius (1.9° Fahrenheit). The other greenhouse gases together will contribute, at a minimum, another half of one degree to the warming trend over the next four decades. The net average global warming of 1.5°C (2.85°F) is approximately equal to the warming that accompanied the transition from the cold of the glacial age to the warmth of the preindustrial world over more than 20 centuries. The changes in climate anticipated as a result of industrial activities dwarf past historical changes.

Energy Measures Required to Slow Effects of Climate Change

Continuation of the world's heavy reliance on the current mix of fossil fuels will bring about shifts in climate that may be of a magnitude comparable to those associated with the transition from a glacial to interglacial epoch. The problem is global; however, the United States is at present responsible for about 26% of the fossil-fuel carbon dioxide added to the atmosphere, and a comparable fraction of the other greenhouse gases. By taking action, the United States can have wide influence, particularly if control measures are taken in concert with other major greenhouse gas producers, such as the Soviet Union, Europe and Japan. This influence was recently illustrated by the successful formulation of an international Convention for the manufacture and use of chlorofluorocarbons and related chemicals. I will briefly describe two major steps that the United States could take that would lower the rate of climate change, and a number of other actions that could contribute to climate stability.

Two developed energy technologies that pose no greenhouse burden are nuclear and hydroelectric. The latter holds only restricted opportunities, since sites for future hydropower development are limited in number. Nuclear power continues to have great potential, but its development has been hampered by a variety of problems, some real, some perceived. The United States, once the world's leader in nuclear energy research and still the world's largest consumer of nuclear power, now faces the future with a demoralized nuclear industry, a confused utility industry, a needlessly apprehensive public and a chaotic regulatory apparatus. The problems of climate change underline the importance of restoring the nuclear energy option. Four major interrelated steps could place nuclear energy on a sound basis. These steps are required if the United States is to remain competitive in the energy-intensive industrial world.

- The issue of high-level waste disposal should be resolved expeditiously. The technical problems are straightforward, though challenging. Other countries, particularly Sweden, have made major advances in defining the geologic conditions under which long-term storage poses no significant hazard over the lifetime of the facility.

- Safety concerns can, to a large extent, be overcome through a combination of technical and regulatory reforms. The United States nuclear industry evolved through individual reactors designed for specific sites. The recognized safety advantages of unit standardization have never been realized, nor have the economic benefits.

- Regulatory reform is essential if the United States is to maintain the nuclear option. Reform measures should draw from the experience gained by the Federal Aviation Administration (FAA) in its regulation of the commercial air industry. Certification of the airplanes (nuclear plants) involves the manufacturer. Certification of pilots (operators) is by the FAA. Other features of the aviation regulatory scheme carry over to nuclear areas and should be considered on their merits; this does not imply endorsement of all FAA procedures.

- Federal government should take the lead in reestablishing a strong program of research in advanced areas of nuclear energy generation. Many applications require smaller reactors than the standard 1,000-plus megawatts currently favored by vendors. These needs have been clearly recognized by the industrialized nations; the Organization for Economic Cooperation and Development and the Nuclear Energy Agency have taken measures to support smaller reactor units. Various technologies are available but need further emphasis, as does research into the many support functions of nuclear plants.

The current worldwide energy-use pattern, particularly in the United States, is a shift toward coal--a greenhouse-intensive fuel. Carbon dioxide is not regulated in any way, nor are there any technologies that have been proposed that would allow cost-effective disposal of this principal waste product of fossil fuel combustion. Indeed, simple thermodynamic considerations rule out the economic recovery and disposal of carbon dioxide from flue gases.

At present, there are no economic incentives to use energy sources that do not emit carbon dioxide, such as nuclear or solar, or fuels which emit significantly less carbon dioxide than competitive fuels. The climatic effect of carbon dioxide is not reflected in the current pricing of energy. When the use-cost is the same between coal and nuclear or coal and natural gas, the end user has no economic incentive to choose the fuel that will result in lower overall societal costs. In standard economic terminology: the relative external costs of altering climate are not borne by the fuels. This policy of neglecting climate change as an external cost stands in stark contrast to the requirement that users of nuclear fuel pay the federal government a fee designed to cover the cost of waste disposal. In the case of fossil fuels, the waste receptacle is the global atmosphere but there is no fee for disposing of the principal industrial waste, carbon dioxide. As a result, the total cost to society inherent in the use of fossil fuels is not adequately taken into account.

A means of internalizing the cost of carbon dioxide waste disposal is to require a federal "user's fee" on carbon emitted to the atmosphere. In principal, the fee should be set at a level that recovers the cost to society of damage resulting from enhanced atmospheric carbon dioxide. The costs to society will be large, since they will involve adjustments in the infrastructure. Provision of new municipal water supplies, construction of barriers against sea encroachment, and new irrigation support dams and canals all require major investments in capital that could otherwise be used to support new enterprises rather than to maintain old, but essential, features of the infrastructure. Such a use of capital depreciates its value; opportunities for technological advance are lost. Clearly, there is no reliable analysis that would meet the most stringent demands of economic theory. An alternative to rigorous analysis is to offer a plan for a gradual implementation (five to ten years) of a fee system structured to place an economic premium on those fuels that would not disrupt future climate. The fee should also be structured to encourage the conservation of the nonrenewable fossil fuels.

In order to illustrate this concept, and to estimate the economic consequences, I consider a fee of one cent for every kilogram of carbon placed in the atmosphere. The charge for burning 1,000 cubic feet of natural gas would be 14 cents; the average charge for burning a barrel of oil, eqivalent to about 6,000 cubic feet of natural gas, would be $1.20; and the average charge for burning a short ton of coal, about 21,500 cubic feet of gas, would be $5.20. These illustrative charges are shown in Table 4.

Table 4

Illustrative Average Carbon Charges for Fuels
(One Cent per kg of Carbon Released)

	Charge per Million Btu (Cents)	Charge	(Dollars)
Natural gas	14.0	per 1000 cu. ft.	0.14
Oil	19.5	per bbl	1.15
Coal	24.0	per short ton	5.20

In 1985, these charges would have brought in a total of 13.4 billion dollars, with 2.5, 6.4 and 4.5 billion resulting from the burning of gas, oil and coal, respectively.

A user charge for carbon thus provides a competitive advantage to noncarbon energy sources, such as nuclear and solar; to low carbon-releasing fuels, such as natural gas relative to coal; and also provides further incentives for energy conservation. A carbon user charge would require a minimum administrative cost, provided the charge is assessed at the point where the energy enters into the commercial stream--the well head for oil and gas, the mine mouth for coal and the port of entry for imports. These flows are already being metered for a variety of commercial and regulatory purposes.

The concept of charging for the disposal of a waste (carbon dioxide) in common property (the atmosphere) is not new. A proposed charge for sulfur dioxide emissions was submitted to the Congress in President Nixon's 1971 Environmental Message. While that proposal failed, there is a rich literature in the economic world commending the internalization of waste disposal costs. Given the pervasive nature of the climate change problem, an approach based on free market economics makes far more sense than further regulation of the energy economy.

By taking steps to restore the viability of nuclear power and initiating economic measures to stem the flow of greenhouse gases into the atmosphere, the United States would signal to the world the seriousness of the climate problem. As in all complex societal problems, a comprehensive approach is needed: there are no "single" solutions. All decisions that relate to energy have an impact on climate change. In and of themselves, the effect of any single decision can be viewed as minor, and therefore should be neglected. However, the cumulative effects of these small decisions can become major. There is a need to sensitize decisionmakers to the long-term energy consequences of their actions. The recent decision by the California Energy Board to promote the sale of methanol as an alternative to gasoline in the Los Angeles basin is an example of energy and environmental policy-making by bits and pieces. Methanol, to be derived initially from natural gas, has significantly lower emissions of carbon monoxide and nitrogen oxides when used in internal combustion engines than does gasoline; methanol's emissions of CO and NO_x are comparable to those from engines burning natural gas.

As an alternative to gasoline, methanol may provide air quality advantages; however, as an air pollution control measure, methanol is not as desirable a fuel as is natural gas. Further, direct burning of natural gas is preferable to methanol on greenhouse grounds; as a synthetic fuel, methanol produced from natural gas and then burned emits significantly more carbon dioxide, as previously discussed. At present, the greenhouse disadvantages of methanol may appear trivial because of the small number of vehicles that would be involved. The greenhouse effect is no longer negligible if methanol is produced from coal with much larger carbon dioxide emissions, and if the number of vehicles multiplies as other nations emulate the United States.

The issue of fueling vehicles from methanol or natural gas touches immediately on fundamental energy policy questions. Clearly, none of these complex problems can be adequately dealt with unless the linkages between such questions as long-term planet warming and resource availability are thoroughly understood and discussed.

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Synthetic fuels use energy to produce energy, thus adding to the climate burden of the planet. Increasing energy efficiency in conversion, transmission or end use conserves energy and lessens the impact on climate. Any energy policy designed to minimize climate effects needs to embrace conservation. The charge for carbon emission is an economic means of encouraging conservation. Measures such as an increased federal tax on gasoline and diesel fuels would place priority on energy conservation in the transportation sector of the energy economy, and would aid in reducing carbon dioxide emissions. Since automotive emissions are directly or indirectly responsible for a significant fraction of other greenhouse gases, such as ozone and methane, measures to reduce energy consumed in automotive transportation would be an economically efficient way of dealing with the climate issue. Similarly, increasing conversion efficiencies from thermal to electrical energy through combined cycle generators, and increasing transmission efficiency through use of low resistive materials, including superconductors, all lessen long-term climate change and should be encouraged by governmental policy.

One means for ensuring that climate consequences are considered in federal decisionmaking is to require such analysis in the Environmental Impact Statement (EIS) procedure under the National Environmental Policy Act (NEPA). While I fully recognize the deficiencies of the bureaucratic nature of the EIS procedure, this mechanism does provide for a check to determine whether the long-term climatic effects of proposed federal actions have been taken into account. For example, the advocacy of methanol as an alternate fuel by EPA's mobile source division clearly qualifies as a federal action with significant climate implications and should be the subject of an EIS review. Proposals for increased excise taxes on gasoline, which are potentially beneficial in a climate sense, should also be subject to an EIS analysis. These examples illustrate the point that a good-faith effort should be made to include impact analyses of all federal actions which have the potential of altering climate. In analyzing the significance-test of the actions, due consideration should be given to the long-term implications of incremental decisions.

The federal government, particularly the Department of Energy, has sponsored research into the physical and biological aspects of climate change. Far less attention has been paid to the analysis of the energy policy issues that this hearing has highlighted. A scientific understanding of the problem, even if imperfect, is an essential prerequisite for policy actions. The analytic community has not yet focused on the means by which scientific findings can be translated into public policy. In large part, this paucity of interest reflects a lack of federal interest and financial support. I hope that this Committee will not only continue its strong support for scientific research on climate change, but will also require the Department of Energy to analyze the policy options that flow from scientific discovery.

I have noted th need for enhanced research in future means of generating electricity using nuclear power. In the past, the Department of Energy has promoted research into coal, while neglecting natural gas. Potential resources of natural gas, particularly gas from shales, tight sands and coal seams received attention during the 1970s, but as the gas bubble developed, resource investigations were dropped. In terms of climate change, use of natural gas is superior to burning coal. In order to assure future gas supplies, research attention should once again be focused on unconventional gas resources, particularly the geopressurized gas deposits of the Gulf Coast and methane hydrates in the continental shelf regions of the United States. These deposits appear to be very large, even though they may be difficult to recover.

This Committee's primary responsibility is to guide the energy and natural resource policy of the United States. Through the use of fossil fuels, the United States and the other industrial powers produce the bulk of gases that are altering the atmosphere and climate. But countries whose economies are primarily linked to the production of raw materials, particularly agriculture, are also capable of changing the climate, through deforestation and soil erosion, processes which place carbon in the atmosphere. In the longer term, all countries will need to collaborate to maintain a stable climate for the global common good. In the shorter term, the United States, working with other industrialized countries, can take the lead in slowing climatic change. In order to do so, a major redirection of the United States' energy policy is required. Nuclear energy must be placed on a sound basis with the resolution of waste disposal and safety problems. The economic advantages of coal--and to a lesser extent oil and natural gas--that stem form the free dumping of waste into the atmosphere must be removed, so that fossil fuels begin to pay for their waste disposal cost to society. Energy conservation slows climate change and should be encouraged; user charges promote conservation in an economically efficient way. Synthetic fuels are economically wasteful and hasten climate change; their use should be discouraged. The actions of the federal government should be subjected to rigorous analysis for implications to climate change through NEPA's environmental impact statement procedure. The federal government should increase support of research into the physical and biological aspects of climate change, and should develop a broad-ranging program to support research on policy options available to deal with potential climate change. Future research emphasis on fossil fuels should shift from coal to unconventional sources of natural gas, including geopressurized gas.

The wise management of energy is essential if we are to prosper. In order to succeed in this task, we need to begin to address the questions relating climate change to energy policy. I would hope that the Committee will continue to exert the leadership in treating these complex problems that it has exhibited and called attention to by holding this hearing.

Senator WIRTH. Thank you for an unusually good and comprehensive statement. We really appreciate your being here and your help.

Mr. Speth.

STATEMENT OF JAMES GUSTAVE SPETH, PRESIDENT, WORLD RESOURCES INSTITUTE

Mr. SPETH. Thank you, Mr. Chairman. It is a great pleasure to be here and to see you again. I want to begin with a personal observation, if I can.

It has been my pleasure to have worked on environmental issues within the Beltway since about 1970. But in that time, I have had a chance to travel around the world and to think about things in the broader perspective.

I have come to the conclusion, having studied this issue for a decade now, and seen it evolve, that this is the most serious environmental issue of them all. And that it demands that kind of response from us all.

It may even be slightly diminishing to refer to it as an environmental issue at all. I think it is one of the most serious economic issues that our country faces and that other countries face.

If you think about the impacts on agriculture, the potential effects there, the sea level rise implications and other things, I think we are talking about huge economic impacts.

It is one of the most serious threats to international stability. If you think of the problems that the destabilizing effects of widespread changes in agricultural potential, for example, sea level rise could have on the Third World and the already-stressed societies there.

And certainly in the context of integrating this issue into the energy, it is one of the most serious issues that this Committee faces. So I commend you for taking it up.

My overall point to you, I think, today would be that despite the uncertainties, and there are real scientific uncertainties and unknowns in this area, that responsible leaders in the public sphere and in the private sphere now really have no choice but to treat this threat as a real one, as an urgent threat, as one requiring serious responses, serious policy changes, and changes not in the distant future but in the near term.

The scientific basis for concern, as you have heard yesterday and today from my friend Gordon MacDonald, the scientific basis for concern and action is compelling. And it has been coming together over the past few years in a way that really does, I think, inspire a certain amount of confidence in terms of what we, that we have to take it seriously.

It may be that the scientific edifices being built will crumble one day. In fact, I think we sort of have to hope that it does, because of the seriousness of the problems that this issue poses for us.

But the fact is that the case is getting steadily stronger and not weaker. So it is my view, Mr. Chairman, that we have got to move forward strongly on both fronts, both from science and on policy. And we have got to bring the two together.

We have got to move this issue into the policy arena. It is not there now. It is not a factor in making energy decisions in the United States, it is not a factor in making decisions about land use, it is not a factor in water projects decisions, it is not a factor in anything except science. And this is a tragic situation that we find ourselves in, and I think we have got to change it.

Some would argue that this issue is not urgent, that we have the time to wait and to see. My view, on the contrary, is that it is already late. Far from having the luxury of additional time, we are late getting started.

As your witnesses yesterday pointed out, we have already committed the world, if the theory is right, to a 1.5 to a 3.5, roughly, Fahrenheit degree temperature increase. We have not realized it yet, but the commitment is there in terms of atmospheric change. Last year, CO_2 emissions were the highest ever.

The lead times necessary to get responses moving are very long. And we have to mobilize ourselves, we have to work with other countries. It will take a long time to get action. And we have to get started today.

And the third point is that there could be some very nasty surprises ahead for us. Certainly the ozone hole in that area was a surprise, and not anticipated. And we could have some nasty surprises on this front as well that make the current consensus in the scientific community that Gordon MacDonald referred to worse, indeed, than it now appears.

Some others might argue that the world would be a little better off if it were a little warmer. And as one debates this issue and considers it, one does hear this argument offered.

I find it a little chilling, frankly, to hear that argument put forward. In the first place, the world, if the models are correct and if current trends continue, is not going to get a little warmer, it is going to get a lot warmer. Unless we do something. A little warmer we may already have bought, so to speak, or banked.

Second, how can anyone know when we are talking about that things might be better off, when we are talking about changes that are truly, will take the atmosphere and the climate of the planet out of anything that humans have experienced? And could do this at any early point in the next century. This is a huge gamble to run.

And third, the fact is that if we look and consider the impacts overall on our country, on other countries, it does seem to me that they are decidedly negative.

Some others claim that no real action is possible. They would concede the problem, they would even concede the urgency of it. But might maintain that there is nothing we can do about it economically, politically.

I think that is a defeatist attitude, which fortunately this country has not taken in the face of many other similar challenges.

I would also maintain that if we could compare the economic and political difficulties of coping with the greenhouse effect with the economic and political difficulties of addressing the greenhouse effect, we would see that, in fact, the economic and political difficulties of dealing with this problem in a preventive way, and recognizing it as an issue and responding to it, will prove in the long run to be less difficult economically, politically, and institutionally than trying to live with all the changes that are in store for us if current trends continue.

A witness testified earlier today that there would be severe economic penalties, or at least economic penalties in the energy area from trying to deal with this problem. I want to return to that issue in a moment.

I think it is very important to find energy policies which do not pose economic penalties, and I think we can indeed find them. That is, not all sectors in the energy area would prosper in the same way.

But I think there are energy strategies that can help address this problem and provide the economic development that we and the Third World and other countries do insist upon.

Also, I think we will find as we look at the responses that are needed to the greenhouse effect that they offer multiple benefits, that the greenhouse effect does not have to bear the full burden of moving forward on some of these issues. And there are many things, many reasons that push us in this direction.

I would also like to point out that the ozone convention which was recently signed is another straw in the wind in favor of optimism about our ability to do something about this problem.

Fifty countries got together, they signed a protocol, and for the first time we are addressing the problem internationally, which people do not see, it is not in their backyards. It is based on a scientific theory. And this to me is extremely encouraging.

Our work has shown that there are approaches in these areas that can make a huge difference, that while we cannot prevent all climate change, in part because of the amount of greenhouse gases that have already built up in the atmosphere, that we can head off the worst of what is in store for us, if we get busy.

So, Mr. Chairman, my own view is that, to respond a bit to your earlier questioning today, I think we do need legislation. I think we need a national climate protection policy.

I support fully what Gordon MacDonald has said, that the National Environmental Policy Act and the environment impact statement could be brought into this process. Indeed, I have written Chairman Hill of the Council on Environmental Quality, urging him to apply the National Environmental Policy Act in this area.

Over a year ago I wrote the letter and they have not done a thing at the Council on Environmental Quality to implement this. So I think Gordon's statement, that if you look at the Tongass National Forest impact statement, you will not find anything in there about this.

But I think that that is not the strongest, I agree that we have got to use NEPA and the impact statement process in this area. But I do not think that is the only thing that we need to do.

I think we need a national climate protection act, a national climate protection policy, that makes this issue a part of the mandate of all Federal agencies, that requires them to be concerned about this, and that ensures that the inter-agency coordination that you were talking about earlier today does, in fact, occur. Because otherwise, my experience in government is that it will not.

If we look at what kind of responses are appropriate, we do see that there are both preventive and adaptive measures that will have to be considered. And I want to stress particularly the preventive steps.

We have to look at each trace gas, we have to see where it is coming from, go back and look first in a technological way at what can be done with this particular trace gas, both in our country and in other countries, to control it.

In this process, it is no secret to anyone here that the energy sector is heavily implicated. The carbon dioxide is half the problem. Fossil fuels may be 90 percent of the carbon dioxide contribution.

And we have got to devise global and regional energy strategies that meet both economic and environmental needs, and then to consider what types of policies are needed to get these strategies implemented.

There have been efforts made in this regard. Our organization and other organizations have sponsored the development of global energy overviews, based on regional building up from national and regional country studies in energy, with the goal of trying to find an energy strategy which does meet this problem, but at the same time meets the economic requirements of the countries involved. And we think we are well underway to identifying such a strategy.

The strategies make heavy use of new technologies in the energy efficiency and energy generation area. And certainly, whether we call it energy conservation or energy efficiency, getting those technologies, the technologies which are at hand and many of which are being used today, used on a much wider scale, is absolutely essential.

And we would be happy to provide the committee with copies of these energy studies, and I refer to them in my testimony.

Energy policy in this country and other countries is going to have to change, if we are going to respond to this problem. We have to get very serious about eliminating subsidies to energy use.

Energy is subsidized in our country, it is subsidized abroad, and I would also like to submit for the record an analysis that we recently did looking at an international cross section of the degree to which energy use is subsidized. It is simply backwards to be subsidizing energy today.

There are regulatory measures which we took up in the 1970's, in the face of the energy crisis, which need to be re-examined, and in my judgment strengthened and extended. We have to look, as Gordon MacDonald was saying, at taxing fossil fuel use.

I think that we are now considering, I trust, I gather from the newspaper, a possible tax on gasoline use in our country, in response to the budget crisis. And I think this is a commendable measure, not only to generate revenue, but also to point the way towards reduction of fossil fuels and to the need for more efficient automobiles.

I would support Gordon MacDonald's suggestion that we give very serious consideration to a carbon tax, and consider that as an international measure. I am not at all advocating the immediate adoption or would not advocate the immediate adoption of such a tax. But I think it forces the issue onto the political horizon. And in the long run, it may be where we end up.

The fossil fuel mix, once you have accomplished all of the energy efficiency improvements that you can accomplish, is extremely important. And in that respect, we want to push towards gas and away from coal and synfuels. The fossil fuel mix is important.

On the nuclear issue, I do disagree, I think, with Gordon MacDonald on his putting that very high on the list. My own view is that by the time you get nuclear energy straightened out and all of the problems that are there, and I could spend some time talking with you about them, we could have preferable alternatives available in the renewable energy area.

And my great fear, given the history of energy R&D expenditures in this country, is that we could return to a day in which we were putting abundant funding into nuclear energy, fission, and fusion, and find once again that the solar energy and other renewable energy resources were being severely shortchanged, while the Japanese continue to make steady progress on that front.

Perhaps one day somewhere down the road there might be a role for nuclear power in this problem. I would not just completely rule it out. And I think we should continue to investigate it as a policy matter and as a research matter.

I do fear very much an overfunding of both so-called clean coal and nuclear, and that these possibilities might eclipse better options.

Whatever we do, we have to do internationally. And I think the dialogue with both the People's Republic and the Soviet Union is absolutely essential. The three countries, the United States, China, and the Soviet Union have perhaps 90 percent of the expected coal reserves.

Moving out of energy, just to mention them, the role of chlorofluorocarbons is extraordinarily important. We have got to continue to build on the protocol recently signed, recently agreed upon in Montreal, and achieve an ultimate phaseout in the use of chlorofluorocarbons, which was the original U.S. position going into the negotiations.

And lastly, I think the role of reforestation and conserving forest resources, particularly in the tropics, is important.

In general, we need a broad-based effort. We do not need a polarized response to this issue. We need for the energy industry and other parts of industry to work with the environmental organizations.

We need the scientists to work with the policy analysts. We need political leaders to work with everybody. And it is going to have to be done on a broad international basis. I hope that we can prevent this issue from becoming polarized.

But I do think that it is high time that it became a policy issue, and even a political issue. As I said earlier, I believe that major policy initiatives will be needed. I think we have wasted a lot of time on the energy front in the last several years.

I think we have been lulled asleep by low energy prices, and in the climate area by a seeming gradualness in climate change, just as we were lulled asleep by a stock market that never seemed to go down. And in both cases I think we have been living in a fool's paradise.

I hope that we do not have to wait for a catastrophe to wake us up to this problem. And the thing that will avoid that, Mr. Chairman, is leadership, leadership from politicians and scientists and others. Thank you.

[The prepared statement of Mr. Speth follows:]

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Summary of Testimony by

James Gustave Speth, President

World Resources Institute

before the Senate Committee on Energy and Natural Resources

November 10, 1987

- The world is already committed to potentially significant changes in climate due to the accumulation of greenhouse gases. By the year 2000, there may be as much as 5.0° F increase in global average temperatures.

- The magnitude of the potential changes that lie ahead is so great that traditional analytical tools are inadequate to characterize the risks. Global warming of several degrees or more that historically required thousands or millions of years may occur in a period of decades. We are doing in generations what previously was measured in epochs.

- The Antarctic ozone hole offers a dramatic warning that changes in the atmospheric system can occur very quickly and unexpectedly, before we can fully understand why.

- The recently completed international agreement to protect the ozone layer gives us hope that an international response to global warming is also possible. However, it will inevitably take a long time to negotiate and implement, and the process should therefore begin as soon as possible.

- While it is too late to avoid some climate change from greenhouse gases, what we do and when we do it can make an enormous difference in the risks we face. A WRI study using four scenarios indicates that policies initiated today could limit global warming to a range of 3.0° to 8.0° F or increase it to more than 25.0° F.

- There is no single, simple solution to the greenhouse problem; however, there are many worthwhile first steps that are largely or entirely justified by other benefits and that together would begin an effective response.

- Energy conservation is the first and most important answer to the greenhouse problem. A WRI study indicates it is technically and economically possible to have substantial global economic growth between now and 2020 with only modest increases in total energy consumption and significant reductions in oil and coal use, but only if we move rapidly to accelerate improvements in energy efficiency.

- Market mechanisms are likely to be the most effective means of promoting energy conservation. We must push for an end to energy price controls and subsidies world-wide. A gasoline tax would also promote efficiency while raising badly needed revenue, and a carbon-based tax would most accurately reflect the climate risk of increased fossil fuel use. We should also promote efficiency through tighter standards, changes in our development assistance priorities, and increased research.

- Not all fuels present an equal danger. Natural gas, particularly when used in high-efficiency technologies, results in much lower CO_2 emissions and should be considered part of a transition to renewable fuels.

- Other important elements of a response to the greenhouse problem are to phase-out CFCs and promote an end to tropical deforestation.

- The necessary policies are all consistent with other environmental, economic, and societal goals.

- The greatest obstacle to action is lack of government leadership. The ozone agreement came about largely because the U.S. took a very strong stand despite little initial support from other countries.

- The Department of Energy has been rigidly resistant to analysis, much less implementation, of effective policies. DOE priorities include substantial increases in U.S. coal production that are in direct conflict with the greenhouse problem.

Testimony of James Gustave Speth

on "Global Climate Change"

before the Senate Committee on Energy and Natural Resources
November 10, 1987

The subject of this hearing is one of the most difficult and important challenges in human history -- the ongoing change in global climate due to the accumulation of greenhouse gases. Emissions of carbon dioxide, methane, chlorofluorocarbons (CFCs) and other gases as by-products of human activity are changing the chemical composition of the atmosphere, gradually warming the earth. This issue is intimately connected to energy policy and management of public lands, the jurisdiction of this Committee.

This committee last directly addressed the greenhouse problem at a hearing in 1980. Since that time, scientific "concern" has grown considerably. We now know with a high degree of confidence that without major changes in patterns of energy use, enormous changes in global climate will occur, and that the consequences could be global disruption on an unprecedented scale: temperature extremes unlike any experienced in human history, devastation of forests and plant life, widespread coastal damage due to sea level rise, and radical changes in the timing and distribution of precipitation. However, policy decisions could have a large effect on the magnitude of these risks.

The issue comes before you framed very differently than it was seven years ago. Global emissions of CO_2 were then stable due to the rise in energy prices; now they are rising steadily. Then we worried only about CO_2; now we know other gases together have an effect roughly equal to CO_2. The issue is no longer whether we need to act but rather what we can do that will be most effective and how the necessary measures can be implemented. While there is no simple solution, we know the direction we need to go: toward energy policies that stabilize and ultimately reduce emissions of greenhouse gases. Every year we delay makes the risk greater and the solutions more difficult.

Your committee must play an important role in this process because of the implications for energy policy and management of the public lands.

The witness list for this hearing includes several eminent authorities on the possible consequences of a global warming. The focus of my testimony is the policy implications of what we know, rather than a review of the science.

The first part discusses the urgency of taking action based on current scientific knowledge. The second part explains that despite the scale of the problem, we can make a difference. The third part discusses directions for government policy response, including both broad priorities and some highly desirable first steps. The fourth part reviews the adequacy of government efforts to date.

I. Policy Implications of Current Scientific Knowledge

The uncertainties associated with the greenhouse problem present unique challenges. However, what we know makes an urgent case for action:

A. Significant climate change may already be inevitable.

Some warming is already inevitable; the longer we delay, the greater the potential for catastrophic effects. The best estimates are that emissions of gases during the last century may have already committed the atmosphere to a warming of 1.3° to 3.6° Fahrenheit. This is in addition to a warming of about 1.0° over the same period. However, the magnitude of the likely changes is far greater than is apparent from these numbers.

Current emissions are increasing the commitment to global warming up to a rate of almost 1.0° F per decade. In the short term, we will do well to avoid an increase in these emissions even if governments begin discussions of policies this year. Thus, as a practical matter, by the year 2000 -- little more than a decade away -- the global commitment may be up to an average warming of almost 5.0° F.

The warming will also not occur uniformly around the globe but is instead expected to increase with latitude. The warming in the northern latitudes could be as much as two to three times the global average. A 5.0° F change in global average could thus mean as much as a 10.0° F change in Alaska.

The implications of changes of this magnitude can best be understood by comparison with the historical climate record. It has been at least 5000 years since the earth was 2.0° F warmer than today, and to find a period 5.0° F warmer than today scientists must go back millions of years. In short, if current emission trends continue, a recent DOE greenhouse assessment concludes, "the resultant average global climatic conditions will be beyond the range of climates that have existed during the historical past and during recent geological times."

B. Climate change may occur suddenly and in unpredictable ways.

Predictions of global warming are based on the assumption that the complex relationship between land, ocean, and atmosphere will remain relatively stable. However, it is quite possible that this will not prove to be the case and that positive feedbacks may accelerate global warming. For example, one possibility is a change in the rate of uptake of carbon dioxide by the oceans after some concentration is exceeded, resulting in a much more rapid atmospheric buildup for the same level of emissions. Recognizing this possibility, the DOE greenhouse report of last year states,

> "The magnitude of these feedbacks could be very important. Yet basic understanding is lacking, even in the short term, of several critical processes." (emphasis added)

The world has recently experienced an example of this sort of unpleasant surprise in the sudden appearance of the Antarctic ozone hole, which was not predicted or even explainable by available models and was not detected and reported until after a reduction of 40 percent. Ozone depletion, like global warming, was expected to occur gradually over future decades, not so soon or so rapidly. We learned only after a 50 percent annual reduction in Antarctic ozone had become an irreversible fact for at least the next century that the existence of ice particles in the atmosphere accelerates the reactions that result in ozone depletion.

The ozone hole is a useful warning, insofar as it acted as an incentive to the recent international agreement to reduce emissions of CFCs by 50 percent over the next decade. We may not be so lucky if similar surprises occur as a consequence of the greenhouse effect. The lesson is clear: we should be humble about relying too much on modelling predictions of the risks of major changes in basic earth systems.

C. Major climate changes could be catastrophic.

Climate models cannot yet predict changes at a scale small enough to suggest consequences for agriculture and other economic activities and for eco-systems. At this stage, scientists are suggesting general conclusions about relatively large-scale regional changes, such as the extreme mid-continent summer drying that Dr. Manabe predicts.

The more fundamental problem, however, is our inability to confidently anticipate the range of potential changes resulting from a wholly new climate regime. Much warmer weather could produce major changes in ocean circulation patterns that would make some regions colder than today. Some scientists have cited the possibility of a large increase in tropical storms. The combination of warmer temperatures and increased CO_2 could radically alter the existing ecological balance among plants and animals, favoring some species at the expense of others. Yet our research is to some extent unavoidably guided by those systems we already know best, such as modern agriculture. We must allow for the possibility, indeed the probability, that effects we do not anticipate will be as great or greater than those we do.

However, the effect of even modest climate fluctuations now is serious enough cause for concern. Summers hot by current standards cause substantial human suffering and economic losses. The summer of 1980, for example, was estimated to have played a role in more than a thousand U.S. deaths and to have cost billions of dollars in crop losses, increased energy use, and other costs. This year's western dryness and the associated fires similarly cost millions of dollars in direct losses and disrupted entire communities for months. Last year's record high water levels in Utah and the Great Lakes region are yet another example.

These changes are small relative to what lies ahead, yet they are justly labeled "disasters." The 1930s dust bowl, which caused a significant migration from several Great Plains states and untold human suffering, may be more analogous to what we should prepare for. The historian Theodore Rabb reminds us, history is

> "...littered with societies devastated, destroyed or merely damaged by climatic forces. From Sri Lanka around 1400 to Greenland around 1700, we can see entire populations either wiped out or forced by immense disruptions to move huge distances, totally reconstitute their economies and polities, and dismantle ways of life centuries old."

D. Global solutions are necessary and will take a long time.

Global climate change is an international problem. All nations are at risk, and many countries must share responsibility for emissions of greenhouse gases. The U.S. and Canada account for only about a fourth of CO_2 emissions, Western Europe about 16 percent, centrally-planned economies about a fourth, and developing nations about 12 percent. The three largest coal consuming nations are China, the U.S., and the USSR.

Unilateral U.S. action without international support cannot provide a complete solution. However, this hardly justifies inaction. Instead, the recognition that international cooperation is required and will be a lengthy process is but another reason to begin seeking such solutions as quickly as possible.

The Ozone Agreement again offers an instructive example. The U.S. took unilateral action against the use of CFCs as an aerosol propellant in 1977 and simultaneously promoted a process of international dialogue. Other countries were in general slow to respond, but in 1981 the United Nations Environment Programme began a more formal process of discussions concerning the feasibility of a convention for the protection of the ozone layer. These negotiations finally bore fruit in September, when 24 countries signed a protocol to reduce CFC emissions in industrialized countries by 50 percent over the next decade.

The ozone negotiations are encouraging as an indication that international environmental cooperation is possible, but illustrative in that significant reductions will occur more than 20 years after discussions were initiated. They also demonstrate the potential benefits of a strong U.S. position, which created a great deal of pressure on our major trading partners. They also show that research and policy can proceed simultaneously; if we had waited for proof of ozone depletion, the ozone negotiations would only be just underway. The euphoria surrounding the ozone agreement may make it somewhat easier to encourage another round of negotiations, but reducing CFC emissions is much easier than changing energy policy. International leadership on this issue is a high priority, a topic I will address more specifically below.

In conclusion, the nature of the problem is such that the risks of inaction are unacceptable. We must begin immediately to identify global responses to the greenhouse effect.

II. We Can Make A Difference

As my earlier comments indicate, we can only slow and moderate the greenhouse effect. Some warming and climate change is already an irreversible fact. We can only hope the consequences are not too great. It should be equally clear that I believe the task of achieving international cooperation to slow and moderate the buildup of greenhouse gases will not be easy. These factors simply add to the urgency of doing what we can, as soon as we can.

On the other hand, we must not succumb to the false logic of thinking that because we cannot do everything, we cannot do anything. What we do and when we do it will make an enormous difference in the risks we face.

A recent WRI study by Dr. Irving Mintzer titled A Matter of Degrees: The Potential for Controlling the Greenhouse Effect, illustrates the cumulative effect of a combination of different policy and economic changes on future emissions of the principal greenhouse gases. Four different scenarios are modelled to portray the consequences of four potential policy packages. **See Appendix 1.**

Mintzer's "Base Case" scenario reflects conventional wisdom regarding population, economic activity and energy growth from 1980 to 2075. No specific policies are introduced to limit the rate of greenhouse gas emissions. No major effort is made to slow the rate of tropical deforestation or its contribution to carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) or carbon monoxide (CO) emissions. No special attention is directed to improving the efficiency of energy use. Environmental concerns do not shape energy policy. Substantially lower than historic rates of growth in CFC emissions are projects for the future, although not as great as should result from the Montreal accords.

The model predicts a commitment to average global warming of 0.9° to 2.6° F above pre-industrial levels by the year 2000.[1] A warming of only 2.0° F -- well within this range -- would put the global temperature far beyond that experience in recorded human history. Simply a continuation of current trends would quite likely commit the atmosphere to this potentially radical change in climate by the turn of the century.

Looking out to 2030, Mintzer's model projects a commitment to average global warming of about 3.0° to 8.0° F, the equivalent of doubling the pre-industrial level of CO_2. This new and very different climate regime is rapidly approaching. Allowing current trends to continue would commit the world to such a warming at a point no farther into the future than World War II is distant in the past. Forty-five years is a relatively short time to make large-scale changes in patterns of industrial activity; studies have shown that new energy supply technologies (which might slow this change) rarely capture as much as half the global market in as little as fifty years.

Mintzer also used his model to investigate scenarios that reflect major changes from current trends. In a "High Emissions" scenario increased use of coal and synfuels is encouraged, deforestation increases, and energy prices continue to ignore the environmental costs of energy use. CFC use grows with rising incomes in other regions at close to the high historic rates observed in the development of the U.S. market. To provide a counterpoint in the analysis, a "Slow Buildup" scenario was constructed to investigate the effect of strong global efforts to introduce solar energy, improve energy efficiency, discourage increased use of solid fuels, and limit deforestation. CFC production and use is controlled in this scenario by international agreements to protect the ozone layer. In the High Emissions case, the rate of emissions growth is accelerated and the date of commitment to the equivalent of doubled CO_2 advances from 2030 to 2015. By contrast, in the Slow Buildup case, this commitment is delayed beyond 2075. Thus, the model results suggest that the commitment to a global warming equivalent to doubling the pre-industrial level of CO_2 can be changed by as much as 60 years as a result of choices before us today and the very near future. The different trajectories that result from these four scenarios are presented in **Appendix 2**.

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[1] More recent estimates of the warming effect, or equilibrium forcing, from greenhouse gases would increase these estimates.

Dr. Mintzer's study documents the basic point that what we do can make an enormous difference, and that there is no single answer. There will have to be many gradual, cumulative changes in the energy ~~we use~~ and the efficiency with which we use it.

In principle, nuclear energy could partially substitute for the burning of fossil fuels, especially coal, and hence reduce the emission of carbon dioxide. For many reasons, however, U.S. utilities are unwilling to undertake new plant construction. And the U.S. public is overwhelmingly opposed to new plants. Operating experience has shown that present nuclear designs are too complicated and place too great a burden on personnel for safe operation. This complexity of design is compounded by having every plant designed differently from every other, making it difficult to transfer learning experience from one plant to another. Complexity also makes safety evaluation difficult and construction expensive.

There is a general belief that if nuclear power is to make a resurgence, a number of difficult conditions will have to be met. Designs will have to be simplified so that reactors are more inherently safe. Operators will have to be better trained. There can be no more TMI or Chernobyl like accidents. And construction productivity will have to dramatically improve to reduce construction costs. Lastly, the high-level waste problem will have to be convincingly solved. It seems highly unlikely that all of these conditions can be met in a period of less than 15 to 20 years, making the possible contribution of nuclear power to the near-term amelioration of the greenhouse problem quite uncertain.

A promising concept for a future generation of nuclear reactors referred to as once-through, high-burn, no recycle systems would utilize low-enriched uranium more efficiently to eliminate reprocessing and the risk of nuclear proliferation. However, we are concerned that research priorities do not over-emphasize the relative importance of nuclear technology. In the time frame it is likely to require to design, test, and build this new technology, many safer and more economic alternatives are likely to become available. We are closer to inexpensive, durable photovoltaic systems than a new nuclear technology, and our research priorities should reflect this promise.

III. Policy Directions

Knowing where we want to go is one problem; how to get there is another. Before discussing a few specific proposals, I want to state at the outset that it is probably unrealistic to think we can define a complete or even adequate set of policy responses until we have expended considerable effort trying to make policy. If politics is the art of the possible, it's impossible to define what's possible without trying. The key is to begin processes that take us in the right direction -- the process is itself a policy.

Nevertheless, we already can say a great deal about some of the basic elements of a meaningful greenhouse policy. There are several basic areas for action, each of which raises numerous possible policy options. All of these strategies are near-term possibilities that are already justified by other environmental, economic, or social goals. In each case, the risk of global climate change simply adds another reason for doing them.

The single most important policy priority is to accelerate improvements in energy efficiency world-wide. This will make it easier to gradually reduce the use of coal and oil. The potential for large improvements in energy efficiency is well documented. For example, DOE's recent "state-of-the-art" assessment of the greenhouse problem states that

> "...low or declining growth rates in CO_2 emissions are possible if energy conservation and shifts to CO_2-benign modes of production are adopted."

Another recent WRI publication describes a low-energy scenario by looking in detail at the services energy is needed to provide and the way those demands can be met most efficiently. The report, Energy for a Sustainable World, was written by an international panel of four distinguished authors: Robert Williams of the United States, Thomas Johansson of Sweden, Amulya Reddy of India, and Jose Goldemberg of Brazil.

By describing what is technically and economically possible (without any further technological developments), they produced results that differ markedly from conventional energy scenarios consistent with optimistic expectations of economic growth. In their scenario, total energy use in 2020 is only slightly larger than current levels, while use of oil and coal -- the predominant sources of CO_2 -- declines sharply. **See Appendix 3.**

Efficiency improvements are also relevant to our generation of electricity, an increasing percentage of total energy consumption in all industrialized countries (about one-third in the U.S. at the current time). A new generation of high-efficiency gas turbines is particularly promising from an economic and environmental standpoint. Its capital cost is low, and it can be installed on a relatively small scale (100 megawatts or less) and much more quickly than large powerplants. Compared to a conventional coal-fired powerplant, CO_2 emissions are reduced by up to two-thirds.

To encourage conservation, out first priority must be to promote rational pricing of energy world-wide. Energy use in countries around the world is currently subsidized to a high degree, as detailed in a new report by WRI economist Mark Kosmo.

For example, in China and India (which together account for 20 percent of world coal consumption) coal consumption is heavily subsidized, discouraging conservation. In both countries, prices are only about 50 percent of world prices. In China, the coal industry earned a negative rate of return in 1984, while subsidies to coal consumers were $10.4 billion -- equivalent to 3.7 percent of the GNP.

Conversely, natural gas prices that are kept artificially low discourage the use of this cleanest fossil fuel in many countries, a lesson we learned in the United States. Since producer prices are often well below production costs, gas is often flared in the search for oil. In addition, low producer prices discourage the construction of extensive transmission and distribution networks. In China, gas production fell by 16 percent from 1979 to 1983 because producer incentives were inadequate. Since trade in natural gas is limited, its underpricing leads to shortages which can only be filled by more tradeable fuels such as fuel oil and coal.

Appendix 4 presents estimates of the delivered costs of natural gas in a number of countries. In all of the countries studied, the costs of delivering natural gas are far below the equivalent prices of heavy fuel oil and coal. If price controls were relaxed and gas prices were allowed to rise to competitive levels, **more** gas would become available and gas would still be cheaper than the competing fuels.

We should go beyond the elimination of subsidies and tax oil or gasoline to discourage increased reliance on imported oil in the interests of the environment and national security. This policy could also raise badly needed revenue. A tax of only 10 cents a gallon would raise $10 billion a year and American consumers would still be paying only half the price charged in Europe and Japan. A more detailed discussion of this proposal is presented in an article by WRI Vice President Jessica Mathews appended to this testimony (**Appendix 5**).

The price of coal should also be raised to reflect the climate risk of CO_2. A carbon-based tax would most accurately reflect the relative difference in the risks of alternative fuels and could also generate substantial revenue.

Regulation also must be part of our efforts to promote conservation. We should tighten existing energy efficiency standards for automobiles and appliances, policies that would also help reduce our dependence on imported oil and the need for costly new powerplants. Such regulations would also help make our appliances and cars more competitive in future world markets. Toyota has already produced a five passenger prototype vehicle that exceeds 90 miles per gallon; American companies should be able to do as well given time and support. **See Appendix 6.**

The second major policy area must be a reexamination of our long-run strategy for the development of new fuels. Considerable effort has been addressed to coal-derived fuels which will only exacerbate the greenhouse problem, while the solar energy program has been totally emasculated. Photovoltaic technology-- sunlight from electricity -- is a particularly promising alternative for the decades to come. Unfortunately, U.S. leadership in this technology has been lost to the Japanese, who not coincidentally continue to provide large government support to this nascent industry.

We will also have to pursue the development of new fuels for transportation. This problem may have to be faced sooner than is commonly thought; many experts are suggesting the possibility of another round of gas lines and price escalation in less than a decade. Two promising alternatives are electric vehicles and hydrogen powered vehicles. The latter concept may soon receive major funding from the Canadian government.

Rational energy pricing would provide a major incentive to the reinvigoration of the renewable energy industry, which has largely collapsed with the reduction in oil prices of the last five years. However, the government role is particularly necessary for research and development of these concepts.

Energy in the developing countries should be a third focus of a greenhouse policy. As noted earlier, these countries now contribute 12 percent of global CO_2 emissions and their consumption is rising much faster than the industrialized world. Countries such as China and India are already major coal users and plan to base much of their development on continued rapid use of this energy source. We obviously cannot expect them to change this policy unless we provide them with practical alternatives.

There is much that can be done to address the energy needs of the developing countries. Contrary to conventional wisdom, energy conservation is just as relevant to these economies as to our own, if not more so; their overall efficiency of energy use is often abysmally low. This is in part because of the lack of incentives that result from subsidized energy, as already discussed, but also a lack of management and technical skills. These needs should be a focus of our aid programs.

Unfortunately, most energy related development assistance and lending by the multilateral development banks is almost entirely directed to conventional, fossil energy development. **See Appendix 7.** This is something the U.S. can change directly, in the case of our own bilateral aid, or indirectly, through our influence on multilateral banks. Such policies can be of enormous help to the developing countries, insofar as they reduce oil-related debt problems and save capital badly needed for other development goals.

Another aspect of energy use in the developing countries of relevance to the greenhouse problem is the escalating destruction of tropical forests. This change is occurring on a massive scale and according to experts may account for as much as 20 percent of global CO_2 emissions. There are many causes of tropical deforestation, but in many places cutting of trees for fuel is a major factor. WRI is working with the World Bank, U.S. AID and other institutions to promote policies to reverse this trend, but much more financial support will be needed.

Another policy focus must be to push for an international phase-out of CFCs, a very potent greenhouse gas. A phase-out was initially urged by the U.S. The ozone agreement calls for a 50 percent reduction, but their continued release will produce a warming effect equivalent to more than 20 percent of current CO_2 emissions and the remaining emissions should all be amenable to substitution with the development of new chemicals.

IV. DOE's Greenhouse Program

Because the greenhouse problem is so intimately related to energy policy, DOE has been the lead agency for CO_2 research and has controlled much of the government's research effort. Unfortunately, DOE has taken the position that policy analysis, much less policy response, is inappropriate until we have more complete scientific information. The rationale for this position was given by Assistant Secretary Trivelpiece at a June 1986 Senate Environment Committee hearing:

> "The existing knowledge base is considered inadequate for recommending changes in the nation's energy system. Cause and effects of climate change are simply too poorly understood to warrant changes in energy policy."

DOE has opposed policy analysis by other agencies, both domestic and international.

Much of the research DOE funds is valuable and worthwhile. However, it is dismaying that DOE has spent substantial amounts to identify crops that may benefit from enhanced atmospheric concentrations of CO_2 -- an issue with very modest global implications -- while refusing to undertake any analysis of policy options. Even the DOE's own commissioned greenhouse science assessment concluded that

> "...the exploration of a variety of policy options for dealing with the complex issue of global climate change, including the cooperative international development and implementation effort that may be necessary, is still a worthwhile initiative, one that must be undertaken far in advance of demonstrable climatic effects."

This problem has been partially redressed by the initiation of policy studies at EPA and the Office of Technology Assessment. However, these agencies are not in a position to make or implement energy policy; only DOE can.

What is much worse, at the highest planning levels DOE remains committed to proposals directly at odds with concerns for global warming. A basic tenet of energy policy continues to be increasing production of oil and gas and promoting so-called "clean coal" technologies. In testimony presented before this Committee on May 20, DOE Assistant Secretary William Martin presented an overview of energy policy that included an increase in domestic coal production of almost 40 percent between 1985 and 2000. Part of this strategy includes expanded efforts to promote U.S. coal exports.

Such dramatic increases in coal production would substantially increase the U.S. contribution to global greenhouse gas emissions undercutting international cooperative efforts. We can hardly convince other countries we are serious about the problem at the same time we are promoting our own coal industry. From a CO_2 standpoint, there is also no such thing as a "clean coal" technology. Indeed, insofar as such technologies reduce overall efficiency, they may result in a net increase in CO_2 emissions.

V. Conclusion

Our knowledge of the greenhouse problem leads to the inescapable conclusion that analysis and implementation of policy responses is now urgent. It is already too late to avoid potentially significant climate change, and every year we delay only increases the risks and the difficulty of finding effective responses. Last year CO_2 emissions reached an all-time high, and continued low oil prices have assured steady growth in CO_2 for the near future. The problem is sure to get worse before it gets better.

What we need most from DOE is leadership developing, promoting, and implementing policy responses. Unfortunately, the agency has so far refused to face up to the problem and continues to give high priority to expanded coal production.

The U.S. should be actively raising the greenhouse issue with China, the Soviet Union, and other nations at the highest levels -- not as a scientific matter, but as a policy problem. The ozone agreement could not have been accomplished without effective advocacy by a handful of officials within the U.S. government and the leadership of the United Nations Environment Program; the same effort will be needed for a greenhouse agreement.

Leadership must also mean elevating the greenhouse problem to a top priority of the Department of Energy, equivalent to oil security and new energy technologies. It is unrealistic to expect some simple "technical fix" to a problem that cuts so deeply across society and indeed across cultures. In this sense, the greenhouse problem is akin to arms control and deserves the same level of effort. Unfortunately, no clear counterpart to this leadership on ozone has yet emerged with respect to the greenhouse effect.

Analysis of policy options has begun under UNEP auspices, but this decision was made despite U.S. opposition. The U.S. has not provided leadership on this issue, and it has resisted efforts by other countries. In this situation, defining workable policies is a more than usually frustrating task.

We can make a difference, but not without a significant change in direction at the highest levels of DOE. This Committee can play a valuable role by insisting that DOE act responsibly.

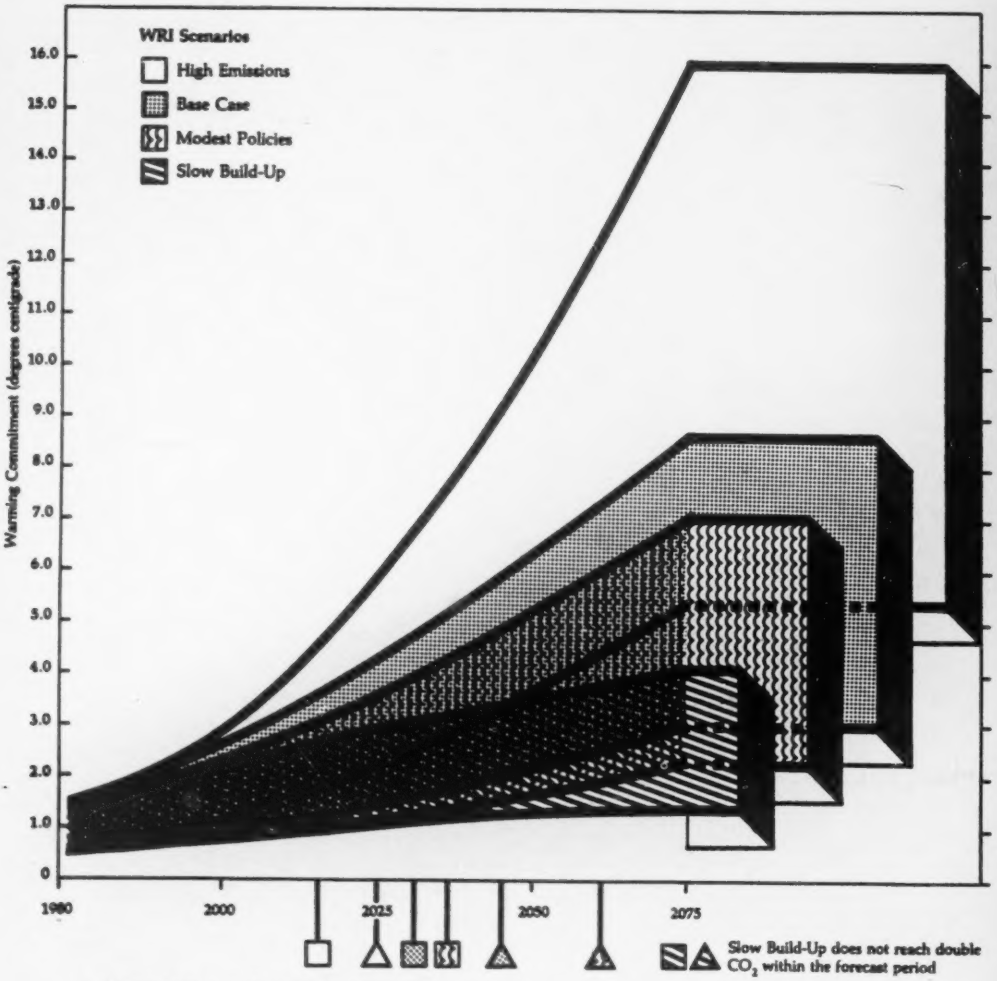
APPENDIX 1

TABLE I. **ENERGY POLICIES IN THE WRI SCENARIOS**

SCENARIO	**RELATED ENERGY MODEL PARAMETER VALUE**	**WARMING COMMITMENT** (Centigrade)
Base Case		
• "Business-As-Usual," the inertial model of growth and change in the world energy industry		1980: 0.5° - 1.5° 2000: 0.9° - 2.6°
• No policies to slow carbon dioxide emissions		2030: 1.6° - 4.7°
• Minimal stimulus to improve end-use efficiency	(Rate of change = 0.8% per year)	2075: 2.9° - 8.6°
• Modest stimulus for synfuels development	(Final Price = $3.15-$4.25 per GJ in 2005)	
• Minimal stimulus for development of solar energy systems	(Final Price = $16.50 per GJ in 2025)	
• No policy to limit tropical deforestation or to encourage reforestation		
• Minimal environmental costs included in price of energy	($0.30 per GJ for coal; $1.00 per GJ for synfuels)	
High Emissions		
• Accelerated growth in energy use is encouraged		1980: 0.5° - 1.5° 2000: 1.0° - 2.9°
• No policies to slow carbon dioxide emissions		2030: 2.3° - 7.0°
• No stimulus to improve end-use efficiency	(Rate of change = 0.2% per year)	2075: 5.3° - 16.0°
• Modest stimulus for increased use of coal	(Rate of Improvement = 0.75% per year)	
• Strong stimulus for synfuels development	(Final Price = $2.75-$3.50 per GJ in 1995)	
• No stimulus for development of solar energy systems	(Final Price = $20.00 per GJ in 2040)	
• Rapid deforestation and conversion of marginal lands to agriculture		
• Token environmental costs included in price of energy	($0.15 per GJ for coal; $0.50 per GJ for synfuels)	
Modest Policies		
• Strong stimulus for improved end-use efficiency	(Rate of change = 1.0% per year)	1980: 0.5° - 1.5° 2000: 0.8° - 2.5°
• Modest stimulus for solar energy	(Final Price = $15.00 per GJ in 2025)	2030: 1.4° - 4.2°
• Substantial efforts at tropical reforestation and ecosystem protection; more intensive rather than extensive agriculture encouraged		2075: 2.3° - 7.0°
• Substantial environmental costs imposed on energy prices to discourage solid fuel use and encourage fuel-switching	($0.60 per GJ for coal; $1.50 per GJ for synfuels)	
Slow Build-up		
• Strong emphasis placed on improving energy efficiency	(Rate of improvement = 1.5% per year)	1980: 0.5° - 1.5° 2000: 0.8° - 2.3°
• Rapid introduction of solar energy encouraged	(Final price = $12.00 per GJ in 2000)	2030: 1.1° - 3.2°
• Major global commitment to reforestation and ecosystem protection		2075: 1.4° - 4.2°
• High environmental costs imposed on energy prices to discourage solid fuel use and encourage fuel-switching	($1.20 per GJ for coal; $3.00 per GJ for synfuels)	

APPENDIX 2

Commitment to Future Warming in the WRI Scenarios



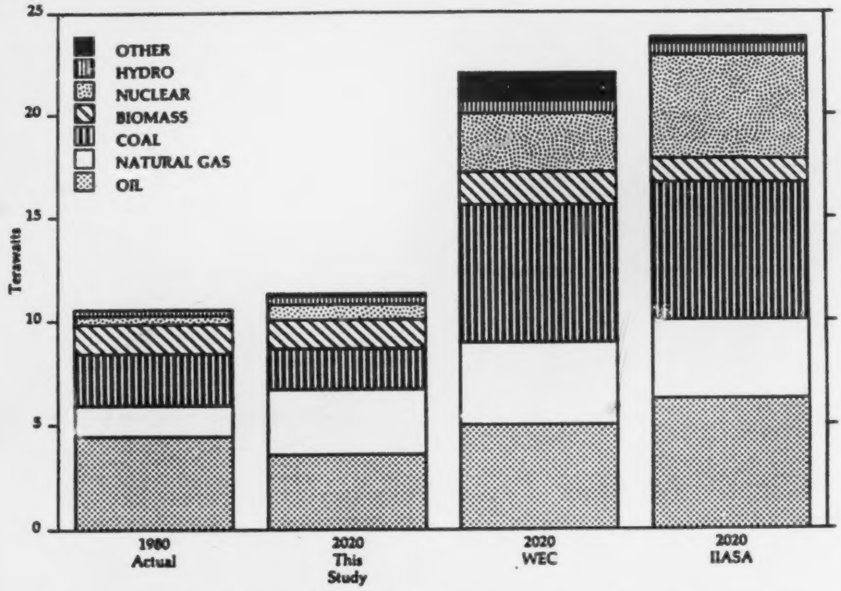
▨▲ Slow Build-Up does not reach double CO_2 within the forecast period

■ Approximate year of commitment to warming equal to 1.5 to 4.5 degrees centigrade above pre-industrial temperature.

▲ Approximate year of commitment to warming equal to 1.5 to 4.5 degrees centigrade above 1980 temperatures.

APPENDIX 3

Alternative Projections of Global Primary Energy Use Disaggregated into the Shares Accounted for by Various Energy Sources



Primary energy use (in billionWatts, or terawatt-years per year [TW]) is shown both for alternative projections to the year 2020 and for 1980. The projections shown are the ones constructed in the present study and both the high and low scenarios advanced in the IIASA (W. Haefele, *et al.*, *Energy in a Finite World—A Global Systems Analysis* [Cambridge, Massachusetts: Ballinger, 1981]) and WEC (World Energy Conference, *Energy 2000-2020: World Prospects and Regional Stresses*, J.R. Frisch, ed. [London: Graham & Trotman, 1983]) studies. For the IIASA and WEC cases the projections shown are averages of the high and low scenarios described in those analyses.

The convention adopted here for measuring the nonfossil-fuel sources of electricity is that hydroelectricity is counted as the energy available in the produced electricity, and nuclear energy is counted as the heat released in nuclear fission, the process from which the produced electricity is derived.

APPENDIX 4

Marginal Cost of Natural Gas (1982 U.S. dollars)

Country	Production Cost ($/MCF)	City Gate Delivery Cost ($/MCF)
Bangladesh	0.24	0.61
Cameroon	1.29	1.79
Egypt	0.65	0.71
India	0.95	1.51
Morocco	1.16	1.71
Nigeria	0.65	1.10
Pakistan	0.36	0.46
Thailand	0.80	1.50
Tanzania	0.61	1.05
Tunisia	0.67	1.60
Average for Heavy Fuel Oil and Coal	----	2.70

APPENDIX 5

Washington Post
Tuesday, November 3, 1987

Jessica Tuchman Mathews

It's Time to Start Raising the Gas Tax

This is one cheap fuel we can't afford.

Whatever else Black Mondays I and II may ultimately prove to mean, they have transformed the political landscape. Policy measures that have been dismissed for years as politically impossible can now at last be judged on their merits. Far and away the most important of these is a gradually rising gasoline tax. Such a tax would produce enough revenue to service and gradually eliminate the debt, thereby solving the financial crisis. Almost as important, it would help put our badly mismanaged energy house in order.

Conferences on energy problems are filling calendars as though it were the 1970s again. But this time, experts who once disagreed fiercely are all saying the same things: U.S. oil production is declining and will continue to decline. Oil imports have already risen from 27 percent of total consumption two years ago to 37 percent today, and are headed straight up. The United States is likely to be 50 percent dependent on imports by the early to mid-1990s.

The energy industry rightly fumes that Washington is doing nothing. Even Interior Secretary Donald Hodel a member of the do-nothing team, predicts the reappearance of gasoline lines as early as 1990, and warns that failing to curb oil imports is like telling oil-producing countries: "Take advantage of us; we're not going to defend ourselves."

The currently popular solution to this mess is an oil import fee. It is the quintessential quick fix: obvious, simple and wrong. While properly designed government regulations can achieve a great deal, one thing no government is equipped to do is to decide what is the "right" price for oil or any other commodity. There is, in addition, the damage that would be done to the credibility of a nation that is ostensibly committed to lowering, not raising, trade barriers. Add to this the number of exceptions to the tariff that would have to be made for friends and allies (Great Britain, Canada, Venezuela, Mexico, perhaps Saudi Arabia) and the ugly conflicts that would have to be managed between those parts of the country that are heavily dependent on oil imports and those that are not, and you have a classic recipe for an unworkable policy whose costs would far outweigh its benefits.

There is a much better way to reduce imports, and that is to reduce consumption in the transportation sector. Alone among all major forms of energy use, transportation is directly tied to oil use, not energy broadly. Two out of every three barrels of oil consumed in the United States are used in vehicles, and gasoline alone accounts for 44 percent of total domestic oil use. The transportation sector is also the choice because, unlike other energy-use sectors, its energy efficiency is not improving, and because the potential for rapid savings is so huge.

The efficiency of the U.S. auto fleet could be boosted by simply raising the current regulatory standard, but such a step would generate no revenue and would leave consumer preferences, which are slowly shifting back toward gas guzzlers, untouched. Today's standard calls for a new car fleet average of 26 miles per gallon, and the U.S. fleet as a whole gets 18 mpg.

This is a substantial improvement over the 13-mpg fleet of 1978, when the standards were imposed (already saving us more than a million barrels per day in oil imports), but it is *nowhere* near what even currently available technology allows. Toyota has produced a prototype car that gets 98 miles per gallon on the EPA combined city-highway test. European producers have models that run in the 60-to-80-mpg range.

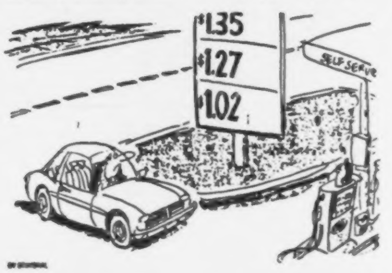
It is impossible to predict how great the future savings would be from a policy that both influenced consumer choices and gave industry a clear signal, with time to adjust and to redirect its formidable research and development capacities.

Last year the average retail price for all types of gasoline in U.S. cities was 93 cents per gallon, down from $1.19 the year before and from the 1981 all-time high of $1.63 (in 1986 dollars). The price won't stay this low for long. Now, therefore, is the economically and psychologically easiest moment to introduce a substantial gasoline tax.

Unpalatable as it may sound, our attachment to cheap gasoline is an anachronistic luxury this country can no longer afford. Current U.S. gasoline consumption is about 100 billion gallons per year, which makes pencil-and-paper policy experiments convenient. Consider a tax that would add 10 cents a year to the current gasoline tax for 10 years, raising it to $1 per gallon by 1998. This would make the total tax about equal to European and Japanese gasoline taxes today.

In its first year the tax would generate $10 billion, enough to provide almost 50 percent of the 1988 Gramm-Rudman-Hollings target. Such a small tax would have little effect on immediate consumption or on economic growth. By 1998, however, the tax would generate a whopping $100 billion per year, and would transform everything from the federal deficit to pressures on world oil prices. (This assumes that the decline in consumption per car roughly offsets the expected rise in number of cars and miles driven.)

Paying more for gasoline is no one's choice, but the choice is not whether to pay more, but when and to whom—ourselves or foreign oil producers? Remember the union song from the great Broadway hit "Pajama Game"? "Seven and a half cents doesn't buy a heck of a lot/Seven and a half cents doesn't mean a thing/But give it to me every hour, 40 hours every week/That's enough for me to be livin' like a king."



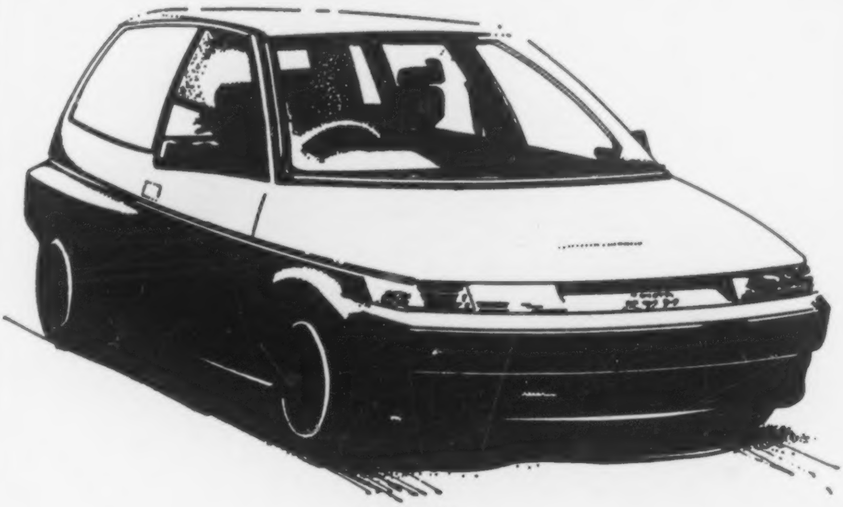
We won't be living like kings, but a phased-in gasoline tax would be enough to buy us reduced energy imports, a smaller trade deficit, a substantial measure of added energy security, reduced pressure on the upward march of world oil prices and high-efficiency cars that would be able to compete with Japanese and European models when oil supplies tighten and prices rise, as they eventually will. All this and a large, continuing and *predictable* flow of funds to reduce the deficit—and leash the bears on Wall Street.

We might some day look back rather fondly on the Crash of '87 as the jolt that brought us to our senses and finally made it possible for us to do the obvious.

The writer is vice president and director of research at the World Resources Institute, a policy research center in Washington.

APPENDIX 6

The Toyota AXV, a Prototype Four- to Five-Passenger, Super Fuel-Efficient Car



Toyota AXV

Introduced in late 1985, the AXV has a fuel economy of 2.4 lhk (98 mpg) on the combined urban/highway test administered by the U.S. Environmental Protection Agency. For comparison, the average U.S. automobile gets about 12.4 lhk (19 mpg), and the average car in the rest of the world about 9.8 lhk (24 mpg). High fuel economy is achieved with the systematic application of presently available technologies: low weight (650 kg [1,430 lb]) from extensive use of plastics and aluminum, low aerodynamic drag, a direct-injection diesel engine (the kind used in trucks), and a continuously variable transmission.

Source: Toyota press release, October 23, 1985.

APPENDIX 7

Table 24. Expenditures of Multilateral and Bilateral Aid Agencies in the Energy Area (millions of current dollars)

	Conventional Power Generation (Hydro, Nuclear, Thermal), Transmission, Distribution; Power Sector Studies	Fossil Fuels Recovery (includes Studies and Training)	New and Renewables (includes Geothermal, Fuelwood)	Technical Assistance, Energy Planning, Other	Total Energy Aid
MULTILATERAL AID					
World Bank (FY 1972–December 1978)	5,210	305	170	–	5,686
Inter-American Development Bank (FY 1972–FY 1978)	2,596	158	4	–	2,758
Asian Development Bank (FY 1972-FY 1978)	1,183	21	0	–	1,204
European Development Fund (to May 1978)	141	–	9	–	150
U.N. Development Programme (to Jan. 1979)	72	23	29	13	137
U.N. Center for Natural Resources, Energy and Transport (to Jan. 1979)	3	5	4	5	17
Subtotal	9,205	512	216	18	9,952
BILATERAL AID					
French Aid (1976–1979)	229	16	30	5	280
Canadian International Development Agency (1978–1979, 1979–1980)	88	0	2	1	91
German Aid (1970–present)	1,925	41	81	48	2,095
Kuwait Fund (FY 1973–FY 1978)	437	99	1	–	536
Netherlands–Dutch Development Cooperation (1970–present)	119	71	7	2	198
U.K. Overseas Devel. Admin. (1973–present)	146	1	3	–	149
U.S. AID (FY 1978–FY 1980)	403	2	96	46	546
Grand Total	12,7 19	757	437	121	14,033
Percentage in Each Sector	91	5	3	1	100

Source: T. Hoffman and B. Johnson, *The World Energy Triangle* (Cambridge, Massachusetts: Ballinger, 1981).

Senator Wirth. Thank you very much, Mr. Speth. Dr. Hidy, before going to you as our final witness, let me note that we have been joined by Senator Bradley. And I was wondering, Senator, if you have any opening statement you might like to make?

Senator Bradley. No, I do not, Mr. Chairman. I am just here to listen and ask a few questions of the witnesses, if time permits.

Let me say that I think these series of hearings is enormously important, and I think we will probably come back to this issue time and time again before we get a fix on what policy implications there are that are practical.

But I think that it is enormously important that we begin to focus on it. And I will have some questions. I would like to be able to submit some questions to the panel in writing, if the time does not permit me to ask them in person.

Senator Wirth. We are leaving the record open, and have talked about that previously. Thank you very much.

Dr. Hidy.

STATEMENT OF DR. GEORGE M. HIDY, VICE PRESIDENT AND DIRECTOR, ENVIRONMENTAL DIVISION, ELECTRIC POWER RESEARCH INSTITUTE, PALO ALTO, CA

Dr. Hidy. Thank you, Mr. Chairman. It is a pleasure to be with you this morning to address this important issue.

It is particularly a pleasure, I think, for me to join you and tell you a little bit about the electric utility industry's research program in this area.

I think before I do that, however, I would like to just note that the consensus on climate change and heating is not really quite as strong as one might assume, I think, from your witnesses so far.

And I would like to point out, just editorially, a couple of observations I think it is important in this particular phenomenon to consider, as is the possibility for increasing temperature.

I think, to a degree, the temperature record length makes a lot of difference in how you interpret what will happen in the future.

For example, if you looked at Dr. Hanson's testimony yesterday, if you took the period between 1940 and 1980, over 40 years, you would find during the period when there was an acceleration, an enormous acceleration in anthropogenic carbon dioxide generation that went into the atmosphere, that the temperature in the world actually went down.

If one, on the other hand, takes the geologic time record, as has been stated, there are periods of time when the temperature has oscillated greatly between ice ages in the last 150,000 years, for example.

And the record that we see in the Antarctic ice would indicate, for example, that the carbon dioxide increased during the time of temperature increases during that period. So one has to ask, during periods of that type, geologically, why the carbon dioxide went up when the temperature went up? Is it a cause or an effect?

It is obviously clear from anybody who grows anything in a greenhouse that vegetation grows when the temperature is increasing. So we have to answer questions of this kind in a scientific sense in the same way that we have to answer questions about the possibility of that temperature increase.

Furthermore, it has not been pointed out in these hearings so far that the radiatively active or absorbing gases in the atmosphere are only one component that leads to temperature changes in the atmosphere.

There is another important component that has not been considered, and that is the suspended particulate matter that exists in the earth's atmosphere.

The particulate matter that exists tends to create, theoretically anyway, hypothetically, a temperature change that goes in the other direction. So one has to consider these elements as well as the absorbing gases.

Let me pass now into summarizing my written statement for you, and indicate what EPRI's research program is at the present time and indicate that the energy industry, the electric energy industry has increased, let us say, through the last decade its awareness of this problem, and is certainly concerned about it.

EPRI, as you well know, is a nonprofit research institute that is funded to manage and plan much of the electric utility industry's basic research on energy and its utilization in this country.

Within the Environment Division of the institution, we have about 35 professionals, environmental and health scientists, who manage a sponsored program of about $30 million a year.

Our program is organized and carefully planned to deal with problems of this kind that are international in scope, as well as a number of other environmental problems that confront the industry.

The basic research that we have conducted to date has produced a contribution to the understanding of how atmospheric emissions of carbon dioxide relate to biogeochemical cycling of carbon, and how other trace gases and suspended particulate matter actually influence the atmospheric radiation balance.

This work, of course, has implications for the generation of electricity and its distribution throughout the United States and the world.

The industry, of course, has a concern for man's perturbation of climate, and that has, we consider, emerged as a major issue that is developing through the last decade. As I am sure you are aware, most of the research has been sponsored by the U.S. Government in this country, and the current effort by the U.S. Government amounts approximately to $140 million, as of this year.

That is not all related, of course, to climate change. The greenhouse program within DOE is approximately 10 percent of that amount.

Through the accumulation of research results over this past decade, as I mentioned, the utility industry has, as has the public, been heightened in its awareness of the greenhouse gas problem and its potential for the future.

However, within EPRI, with our work, we have a limited budget, as everyone does, and a close relationship with the industry in terms of how we spend that budget.

To date, because of the heavy Federal investment in climate research, and the uncertainty and the significance of what that research has indicated to us, as it relates to the utility industry in this country, our work has actually been modest.

In pointing that out, I should mention that a very coarse assessment of the utility contribution to the global CO² burden is that fossil fuel combustion-generated electricity in this country amounts to only a few percent of the total global carbon dioxide emissions.

Thus, if one were to eliminate, let us say, all fuel combustion to produce electricity in this country, it would affect the global condition only in a very small way. And in this sense, then, this medication, of course, would be impractical based on our current energy production picture.

The utility industry, then, views this issue as a significant one, but not one that it has considered to be critical in placing its research resources to date.

Even though the utility operations appear to be minor, we have undertaken, as I mentioned before, a program in trying to understand much better how the biosphere acts with the atmosphere in dealing with carbon dioxide.

This work has involved several projects that are already complete. Work in progress has included the development of a very complex ocean atmosphere biosphere model, through work sponsored at the Scripps Oceanographic Institution, along with a study of biosphere atmosphere ocean interactions that relate to conditions over geological time scales. This work we expect to be long-term in its character and on a continuing basis.

There are two additional areas of EPRI research that have arisen——

Senator WIRTH. Dr. Hidy, if I might, I have just been scanning your written statement, and provides that information.

Maybe we could get you, if we might, to give EPRI's summary and conclusions about where we ought to go in the area of public policy. Could we do that?

Dr. HIDY. Certainly. I would like to mention for the record, Mr. Chairman, just very briefly the areas that we are increasingly concerned about, so that we do not miss them.

And that is first of all the question of nitrous oxides and their emissions from the electric power plants. In fossil fuel combustion, we consider this a unique area for our research that is a niche that we would like to fill in the Federal Government program.

The second area that relates to our looking at research policy is, given worst case conditions, if indeed the temperature changes were to occur, what does this really mean for the electric utility industry?

This is very important, I believe, in the industry's view of the situation in the sense that the energy production that we foresee in the future in the form of electricity will be inexorably tied with whatever can be done, let us say, in the worst case situation, to provide the public with the resources, energy resources to deal with such a problem.

And we intend, as part of our research program, to actually look into this in a much greater detail than has been done on a national scale before.

And I should mention in a preliminary study of this kind, Mr. Chairman, that the problem is indeed significant in terms of electrical demand of something on the order in one State alone of 10 to 20 percent increase in demand, should that temperature change take place.

So it is not a trivial problem, and we need to start looking at it at this point in time to make sure we understand its implications.

To move on then to science policy considerations, then, EPRI's position basically is that, on behalf of the industry, that we have to be closely tied to this program on an international scale.

Our position is to continue a modest research program, concentrating on the biosphere and look into these two other areas of nitrous oxide, and the risk assessment aspects of the problem.

In the past, EPRI has worked very closely with the Federal Government. We intend to do so in a coordinate way in this particular area.

As far as the Institute's position is concerned, we feel in examining the science, through our advisors and through our internal staff at this point, it does not appear that any precipitous action is warranted in the policy area at this point.

But certainly we would welcome and encourage the government to intensify its research more, not only on the scientific aspects of the problem, but also on the risk assessment areas, of what the public and society on a world scale will need to do, should these environmental changes in our atmosphere take place. Thank you.

[The prepared statement of Dr. Hidy follows:]

Committee on Energy and Natural Resources

U.S. Senate

November 10, 1987

Testimony of George M. Hidy

My name is George M. Hidy. I am Vice President and Director of the Electric Power Research Institute's (EPRI) Environment Division. I am also a member of the Executive Committee of the Environmental Protection Agency's Science Advisory Board.

EPRI is a non-profit research organization whose goal is to ensure that consumers are provided with safe and economic electric power. The Institute is supported by some 500 member companies accounting for nearly two-thirds of the nation's electric power sales. EPRI was incorporated in 1972 and has had a substantial and continuing research program on the health and environmental implications of utility activities, including research on air quality phenomena and climate modification. The Institute currently employs about 35 environmental and health scientists who manage a $30 million research program on environmental and related health sciences. Our professionals are acknowledged experts in their fields; they have served on National Academy of Science committees, as presidents of professional societies, as editors of prestigious scientific journals, as members of EPA's Science Advisory Boards, and as advisors to numerous governmental and scientific bodies. The organizations that conduct this work for EPRI include universities, major research laboratories including National Laboratories, and consulting firms.

Today, I am here at your request to discuss certain aspects of EPRI's programs and the possible climate change resulting from increases of radiatively absorbing gases in the earth's atmosphere.

EPRI's research program is carefully planned to address environmental issues of international scope as part of its activities. In response to the industry concerns, EPRI has maintained a liaison with researchers in the area of climate change. The basic research to date has produced a contribution to understanding how atmospheric emissions relate to the biogeochemical cycling of carbon dioxide, and how other trace gases and suspended particles influence the atmospheric radiation balance. The work has implications for the generation and distribution of electricity in the United States and the world. These are noted below.

Theoretical calculations of the behavior of the earth's atmosphere suggest that its heating and cooling depend on accumulation of certain radiatively active gases like carbon dioxide (CO_2), water vapor, nitrous oxide (N_2O), methane (CH_4), and chloro-fluoro hydrocarbons. If the concentration of these gases changes, the heating of the atmosphere would change, resulting in possible weather disruption as well as temperature changes near (or at) the ground. Suspended particles also will interact with radiation, possibly causing surface temperature changes analogous to gases. Scientific support for a hypothesis of atmospheric warming has come largely from observations that atmospheric CO_2 has increased in the 20th century, and at the same time, there is evidence of a global surface temperature increase. The increase in global concentration of atmospheric CO_2 is believed to be the result of fossil fuel combustion, combined with reduction in the areal distribution of vegetation, the latter leading to less CO_2 being taken up in plant growth and more carbon released as CO_2 through plant decay. In the past decade, some scientists have reported analyses that appear to give evidence of increases in the surface temperature of the earth that is consistent with the calculations. Others consider this evidence inconclusive, based on available data records, to warrant such conclusions.

The concern for man's perturbation of climate has emerged from a major climate research effort mainly sponsored by the U.S. government since the 1960s. The current effort funded by the government is substantial, evidently about $140,000,000 annually, in 1987. Only a fraction of this funding is devoted to the so-called "greenhouse" gas effect, but nevertheless the research investment is significant in scope.

The accumulation of research results over the past decade has heightened the awareness of the electric utility industry about the greenhouse gas question. At EPRI, we have followed closely the developments on this subject for a number of years, as well as conducting research on related topics. Because of the heavy federal investment in climate research and an uncertainty about the significance of this question relative to other utility-environmental issues, EPRI's research has remained modest on this subject. A coarse assessment suggests a U.S. utility contribution to the global CO_2 burden of only a few percent. The elimination of all fossil fuel combustion for U.S. electricity production would affect the global condition only in a very small way. This mitigation measure, of course, would be impractical if not impossible to achieve in the light of the availability and environmental constraints of alternate fuel sources.

Even though the utility operation's role appears to be minor, we have undertaken a modest program of research on CO_2-biosphere interactions that has permitted an improved understanding of the complexities of the geochemical behavior of CO_2. The work is in progress and is intended to provide an improved understanding of global atmospheric processes and their interaction with the land biosphere and the ocean on mediating atmospheric CO_2.

Since 1980, several projects on the CO_2 issue have been completed. Currently two projects on the global carbon cycle are progressing under EPRI sponsorship at the Scripps Institute of Oceanography. The first is aimed at developing a comprehensive atmosphere-ocean-biosphere model to account for CO_2 changes and climate effects. The second focuses on the carbon exchange between the ocean and the atmosphere over geologic time scales.

The first project is motivated by the need to synthesize a variety of information about the carbon cycle. The nearly thirty years of systematic global observations of atmospheric carbon dioxide concentrations have shown not only an increase in CO_2 levels over time, but have revealed detailed manifestations of the variations of carbon globally by examination of the data record. There is a clear seasonal cycle of peaks and troughs in atmospheric CO_2 levels, superimposed on the long-term trend in increasing concentration. In addition, the amplitude of these seasonable cycles - the peak-to-trough height - has apparently increased in recent years. There are, as well, geographic variations evident, the most prominent being a shift in the timing of peaks and troughs between stations in the Northern Hemisphere and those south of the equator. Although this shift reflects the 6-month difference in the onset of the growing season between hemispheres, a full explanation requires consideration of the time lag for a "pulse" of CO_2 entering the atmosphere to be distributed globally and reach equilibrium with the surface. This CO_2 behavior needs to be well explained to understand the atmosphere-biosphere cycling. Toward this goal, Dr. Keeling is developing an integrated model of the dynamics of total and isotopic carbon in the ocean-land-atmosphere system.

The objective of the work is to develop a comprehensive model of the carbon cycle with a predictive capability, allowing the sensitivity of atmospheric CO_2 levels to any of the cycle's sources or sinks to be evaluated. The model incorporates the effects of terrestrial plants and of fossil fuel inputs of CO_2, in order to explain the observed spatial and temporal properties of atmospheric CO_2. The approach has been to link separate models for ocean circulation, atmospheric dynamics, land plant activity, and human input of CO_2, through the use of transfer processes.

In the second EPRI sponsored study, Dr. Keir is examining how carbon dynamics in the ocean, and exchange between the ocean and atmosphere, might have changed with climate fluctuations since the last ice age. The model resolves the ocean into several compartments to simulate observed behavior of carbonates and other compounds on the ocean sediment record. The work is aimed at estimating circulation patterns in the prehistoric oceans by using the present-day ocean circulation and observed bottom-layer properties to deduce geographic differences in carbon dynamics. These differences, combined with data from ice cores and bottom sediment samples, allow construction of ocean circulation patterns for earlier periods which, in turn, provide information on global wind and temperature fields to reconstruct prehistoric climates in relation to the carbon cycle. Through an understanding of geologic history, the current changes can be placed in perspective, especially with respect to man's activities.

Two additional areas for EPRI research have arisen that appear to be related to the electric utility industry's operations. These concern the industry's response to another radiatively "active" gas, nitrous oxide (N_2O), and the issue of potential change in societal infrastructure should the predicted global surface heating actually take place over the next century.

Recent observations suggest that atmospheric N_20 concentrations are increasing. This gas is thought to be primarily biogenic in origin and non-reactive in the atmosphere below about 15 km altitude. N_20 is very low in concentration compared with CO_2; nevertheless, its ability to absorb sunlight in similar wavelengths suggests that its increase may be a factor in global heating. The increases in N_20 thought to be occurring have an uncertain origin, and may be due to both increased fossil fuel use, and increased cultivation of fertilized land, producing more N_20.

Very preliminary data suggest that traces of N_20, in addition to nitric oxide (N0) and nitrogen dioxide ($N0_2$), may be found in emissions from fossil fuel combustion sources in addition to nitric oxide (N0) and nitrogen dioxide ($N0_2$). With increases in combustion would come increases in N_20 emissions worldwide.

This aspect of the greenhouse gas question is poorly understood, and offers an opportunity for EPRI to make a useful contribution to international climate research with its limited funding resources. Thus we are considering initiating exploratory study to better characterize N_20 sources in the 1988-1989 period.

In the second area, we at EPRI believe that the electric utility industry, like other industries, needs to begin considering the consequences to its operations of potential changes in climate. Utilities may be required to make important adjustments in electricity supply and distribution should significant atmospheric alterations come to pass. For example, climate change may affect 1) air conditioning and heating demands, 2) urban and agricultural water pumping demands, 3) hydroelectric capacity, 4) delivery system reliability and 5) utility operations in vulnerable coastal regions. Impacts such as these may have important implications for how electric utilities do business in the future. Research is needed to determine the nature and the magnitude of these impacts and to provide a perspective on the industry response to such changes.

A recent study by ICF Incorporated made a first step in this direction.* The study, which was cofunded by the Edison Electric Institute (EEI), EPRI, New York State ERDA and U.S. EPA, examined the implications of an uncertain future climate for two cases: the New York State utility system and a southeastern utility. Focusing on the year 2015, the analysis found that in both cases, moderately rapid climate change increased generating capacity requirements by 10-20%, with associated increases in the costs of electricity production projected at hundreds of millions of dollars.

The ICF analysis represents an initial attempt at analyzing the potential impacts of climate change on electric utilities. There are opportunities for improving the data, assumptions, analytic approaches and estimation methods that were used. Nevertheless, the preliminary results are provocative. This is another area in which EPRI hopes to continue to make a contribution in the future.

While the emerging research on the role of radiatively active gases has shed light on the potential for climate change, our scientists note that these are hypothetical, with our limited understanding of the atmosphere-biosphere interactions. Further, we note that the presence of suspended particles (aerosol particles) theoretically will tend to offset the effect of the radiatively active gases. Also, at least in the case of CO_2 and N_2O, interactions with the biosphere are essential ingredients in the scientific phenomenon. These are poorly understood, particularly for terrestrial conditions. The climate research to date has not given a complete picture of the complexities of the phenomenon. Studies of increasing complexity and sophistication will be necessary to obtain a picture of the future to rationalize a long range policy on this issue. Because the phenomenon is so complex and is global in character, it is premature to consider an action beyond intensified research on the potential environmental and economic impact of climate change.

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* "Potential Impacts of Climate Change on Electric Utilities," prepared for the Edison Electric Institute, Electric Power Research Institute, New York State Energy Research and Development Authority and the U.S. Environmental Protection Agency by ICF Incorporated, November 1987.

Given the current state of knowledge, EPRI plans to continue its interest in climate research, and participate actively in this research to the degree possible within its resources. We welcome the opportunity to join in a partnership with the federal government and the private sector in sponsorship, in much the same way as we have in other environmental issues of common concern.

Senator WIRTH. Thank you very much. Let me ask you to comment on clean coal technologies.

We heard Dr. Koomanoff earlier this morning talk about how clean coal technologies might help us to increase energy efficiency, and that that might be an important interim step to take as we go to cleaner energy technologies later on down the line.

One, do you agree with that, particularly you, Dr. MacDonald? And second, are any of you aware of any scientific analysis of various technologies for refining coal into methanol, that in fact might be technologies that ought to be pursued? Are there differences among technologies that we ought to be encouraging and pursuing?

I gather in all of this that there is an inevitability, from everything we heard this morning and yesterday, to the use of a great deal of coal. And if that is the case, are there ways in which we ought to be encouraging different technologies in the coal area that might be helpful? Dr. MacDonald?

Dr. MACDONALD. First on the question of energy efficiency, clearly any steps that can be taken to increase the efficiency of coal would assist in dealing with the long-term climate change. And I agree, coal is going to be a significant energy resource for the foreseeable future.

But in terms of other fossil fuels, coal suffers. Whether you burn it directly, currently with maybe 33 percent, 35 percent efficiency and utilities, or with advanced methods of burning coal where you get somewhat higher efficiencies, these still result in the emission of significantly greater quantities of carbon dioxide than getting the same amount of energy, thermal energy from, let us say, natural gas or from oil. And certainly, much more than from nuclear power.

In terms of conversion of coal to methanol, I have, at various stages dating back to the 1970's when there was a great deal of interest in synthetic fuels, looked at the various processes that have been suggested.

And even under the best of circumstances, let us say, relative to natural gas, getting the same amount of energy from natural gas, as from methanol converted from coal, you would double the carbon dioxide produced for the same amount of energy delivered.

Senator WIRTH. Excuse me, I am sorry. Could you do that last paragraph again?

Dr. MACDONALD. The last paragraph was just that if you convert coal to methanol, using the most favorable estimates for technology that would be available, the amount of carbon dioxide that you would emit in powering an automobile, relative to natural gas, it would emit about twice as much carbon dioxide as you would by powering the automobile, same performance, from natural gas.

Relative to gasoline, it is about 40 percent more than gasoline. Methanol does have certain advantages, in terms of urban air pollution, the question of ozone, and so forth. But so does natural gas.

So in a competition between natural gas and methanol, there is no question that natural gas is to be favored environmentally.

Senator WIRTH. Mr. Speth or Dr. Hidy, do either of you have any comments on clean coal technology or the conversion of coal to methanol?

Mr. **Speth**. Mr. Chairman, I think by far the critical issue is total energy use.

If total energy use is kept, and energy growth is kept at a very low level through rapid introductions of efficiency improvements, then there are a lot of supply ways of going about solving this problem.

But in the energy analysis that we have done, which I want to submit for the record, in a report called, Energy For A Sustainable World, it was prepared over a period of several years by an international team of leading energy experts. It was based on Third World analysis and industrial country analysis.

We put together an energy future that actually involves very little, if any, total energy growth between today and the year 2020. In that scenario, and it achieves the economic aspirations of both industrial and developing countries.

So energy growth in this possible future, does not grow much at all. But in that future, natural gas use increases about threefold to meet the requirements of both economic and environmental requirements that were imposed.

Coal use declines by about a third, and oil use declines by about a fourth. And I think that this, in some ways, is the kind of future for our country and for the world that Dr. MacDonald and others have been describing.

Coal does not appear, is on a decline in the decades ahead. Oil is on a decline. It is not drastic, it is gradual, in both cases. And natural gas use is going up. The total fossil fuel use overall stays about the same in the decades ahead.

And it is only if this happens, only in such a scenario in which total fossil fuel use stays about the same, are we going to do anything meaningful about the climate change and the greenhouse effect issue.

Senator **Wirth**. As a footnote to your discussion, what should we be doing, if anything, about pricing natural gas right now? If you were a nonpolitical god, what would you do?

Dr. **MacDonald**. Much of the problem surrounding the natural gas industry has resulted from a complex web of regulations, only some of which are we working our way out of.

That if natural gas had indeed been priced at its value, rather than at an artificial, or having an artificial element to it, I think it would continue to remain economically competitive with oil, and certainly with coal, and at the same time have a price sufficient to induce further exploration for natural gas.

Senator **Wirth**. What does that mean, Dr. MacDonald? What should we do? If you were advising, which I am asking you to do right now, the Energy Committee, what should we do about the price of natural gas?

Dr. **MacDonald**. Insofar as is humanly possible, deregulate natural gas completely.

Senator **Wirth**. Mr. Speth, do you agree with that?

Mr. **Speth**. Yes.

Senator **Wirth**. Dr. Hidy?

Dr. **Hidy**. I think in general I would agree with that. However, as a chemical engineer, I get a bad case of nerves when talking about burning natural gas as opposed to other fuels, because it is a very high-quality hydrocarbon, relative to what we have available to us, and it is a very important high-quality material that we make chemicals out of.

So one has to trade off burning it, let us say, as you would a piece of wood, versus what the valuable end products could be. So it is not a simple case of just burning natural gas in the context of a hearing here.

Senator WIRTH. How do you respond to that, Dr. MacDonald?

Dr. MACDONALD. Yes, natural gas does have a very high quality, since it is composed solely of carbon and hydrogen, and does not contain the impurities that other fossil fuels have.

Yet it has been historically priced well below its value. And it is a long history, a very complicated history, and as a result we have not given natural gas the attention that it has.

It has been a byproduct of the major oil companies. It has not been a target of exploration, except among independents and to a very small degree.

So I think there is a real need for a new emphasis on natural gas, including going back and starting to look once again at some of the unconventional gas resources, which I mentioned we did do in the 1970's and then abandoned as the gas bubble developed and everybody said, well, there is no need to go after hard-to-get natural gas.

I think in the long-term we need to exploit the various forms in which natural gas is found within the earth, and that the quantities of natural gas in these deposits will turn out to be extremely large.

Senator WIRTH. Should we, for example, be doing a great deal more research on the tight sands, tight natural gas sands? Or should we leave it up to the marketplace to do that?

Dr. MACDONALD. In the case of tight sands, probably there is still a need for the Federal Government to provide research.

Certainly in the far out natural gas resources, geopressurized gas, that is gas under high pressure dissolved in fluids, and methane hydrates, that is solid natural gas trapped in the continental shelf in the very cold regions, are highly risky areas of exploration at present. And there, I think, the government does have an appropriate role.

Tight sands comes right about at the breaking point where I personally would advocate Federal support of research. I think I would come out on the side of yes, the Federal government still continues to have a role there. But a much more important role in the farther out gas, geopressurized gas and methane hydrates.

Senator WIRTH. Going back to the question of looking at coal, you all did something called a cool water plant.

Dr. HIDY. Yes, that is correct.

Senator WIRTH. That is a very efficient use of coal and very low——

Dr. HIDY. And very pollution-free, except for carbon dioxide. That is correct. That is a, we feel, a showcase for EPRI.

Senator WIRTH. Does that have any carbon dioxide benefit?

Dr. HIDY. Yes, it has carbon dioxide emissions, and it is not controlled with respect to carbon dioxide.

Senator WIRTH. No, I asked, does that have any carbon dioxide benefits?

Dr. HIDY. Oh, I am sorry. No, unfortunately, once you burn the fuel, the carbon dioxide goes ultimately. So Dr. MacDonald's point, I think, is quite correct.

Senator WIRTH. Is there anything you can do on that front?

Dr. HIDY. We have not explored the actual control of carbon dioxide from that plant.

Senator WIRTH. You what?

Dr. HIDY. We have not explored the initial control——

Senator WIRTH. Given the focus on this, why has that not been done? It just is not technically possible? Or it was not a priority?

Dr. HIDY. It certainly technically is possible through chemical means to remove the carbon dioxide. It has not been considered to be, let us say, an end-of-pipeline emission control technology that the industry has been concerned with today.

Senator WIRTH. I do not understand what that means. Why have you not done it? It just was not a priority?

Dr. HIDY. It was not a priority, relative to our resolving the sulfur and nitrogen oxide——

Senator WIRTH. You were focused on the sulfur and nitrogen problem. But given the growth of this, the carbon dioxide problem, is this something you are going to be focused on then?

Dr. HIDY. We have done some exploratory investigations on the feasibility of emission control for carbon dioxide. It is, as you would guess, extremely expensive to do it.

Senator WIRTH. It is.

Dr. HIDY. Our position, I think, would be to agree with Dr. MacDonald that fuel alternatives ought to be looked at very carefully in that light, in the sense that, as you might guess, the electric utility industry would like to make much better use of its nuclear power capability.

Senator WIRTH. Dr. MacDonald?

Dr. MACDONALD. Yes, Mr. Chairman, on the issue of control of CO_2 emissions, there has been some work, including that referred to by Dr. Hidy at EPRI.

Brookhaven has carried out some. I have been involved in analysis. And basically there are just some very simple thermodynamic facts of life.

Once you combine carbon with oxygen to stuff it back into the earth or otherwise dispose of it, you essentially have to use very nearly the same amount of energy that you got out of it in the burning process to begin with.

So it does not look like even in principle would it be possible to economically remove carbon dioxide. And it is because of that that this problem is so serious. It is quite unlike the SO_2 removal, where industry has done an extremely good job of providing means of removing SO_2 from the flue gases.

CO_2 is basically going back and trying to reverse the process out of which you got the energy to begin with. And to do that means that you are going to have to expend essentially the same amount of energy. So there is no net gain.

That is why the issue is as serious as some of us think it is.

Senator WIRTH. At the bottom of page two, Dr. MacDonald, expand a little bit more on the little ice age that devastated 17th century Europe.

Dr. Hidy was saying this was the opposite of the impacts that you are thinking about looking at, things getting warmer rather than colder. What happened?

Dr. MACDONALD. During the late 1500's, early 1600's and 1700's in Europe, there were a series of very cold spells in which there were agricultural failures in wheat, barley, rye, in the northernmost parts of Europe, Scandinavia and in particular, Germany, and England.

Famine was then accompanied by a recurrence of the black plague. These were all the result of a downswing in temperature and associated wide swings in precipitation.

Dr. Hidy is completely correct that there are many factors affecting climate. At this time, or about this time was a period in which the sun went through an extremely quiet period. Very few sunspots, so that the solar radiation may have been less than at other times.

There are other reasons to suspect that even the internal mechanisms of the atmosphere could give you a swing. But one has to recall that that swing really corresponded only to an average temperature change the globe over—and this is an estimated figure because obviously we did not have instrumentation—of a few tenths of a degree at most. Two or three-tenths of a degree.

Small compared to the changes that we are now talking about. The changes, of course, going in the opposite direction of becoming warmer, and progressively warmer.

One can then ask a very important question, which we do not know the answer to, though one can speculate, is as the climate changes gradually, are these swings, either very warm periods or very cold periods, likely to be more probable? Or are we going to have a more even climate?

Because it is the swings that can cause the disasters in agriculture and associated loss of life, with disease, that were associated with the little ice age.

Senator WIRTH. The point of that is that there was an enormous impact on civilization, mankind, of a change of a few tenths of one degree. And we are looking at more than a few tenths of one degree.

We are looking at a much bigger change, and if we extrapolate from the experience in the 17th century to look at what the experience might be in the 21st century, it is going to be very severe?

Dr. MACDONALD. Yes, and the historical instances of warming with accompanying droughts.

And I mentioned that in my testimony, in the period 1500 to 1200 B.C., much of Central Asia went through extensive periods of drought, with the driving out of the people from the Anatolia Plateau, from the Hittites moving down into Greece, a sort of mass migration, resulting from an extended series of droughts in the Central Asia, reflected in the Chinese history of the same time.

So there are numerous instances in history where both warmer spells and cooler spells have had significant impact on where people live, how they live. And as I point out in the testimony, we are in a much better or more resistant position to take these swings into account.

But not all peoples of the world are in a similarly favored position. And even industrialized societies can suffer under these swings in climate.

Senator WIRTH. We had promised you all a 12 departure, and it is now 12.

Let me ask you if any of you have comments that you would like to make, or comments on what others have said, before we close the hearing.

Dr. HIDY. Mr. Chairman, just a very brief comment on energy efficiency.

I think it is worth noting that the electric utility industry is a responsible party in this area, and has great concern for conservation and efficiency.

And indeed, its program at EPRI, a portion of it is aimed in this direction, including looking at areas of superconductivity for improving our situation with respect to both generation and distribution.

We also are doing a great deal of work in improving appliances, electrical appliances, and how they use electricity, so that I think that is an important duty and responsibility the industry has, and it is certainly looking after it.

Senator WIRTH. Thank you all very much. We are pleased to have you here. Your testimony was very, very helpful and very comprehensive. And you all have made a significant contribution.

Once again, we thank you. And we will be adjourned.

[Whereupon, at 12 noon, the hearing was adjourned.]

[Subsequent to the hearings the National Science Foundation submitted the following statement:]

STATEMENT OF

DR. ROBERT CORELL
ASSISTANT DIRECTOR FOR GEOSCIENCES
NATIONAL SCIENCE FOUNDATION

FOR THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES

UNITED STATES SENATE

November 9, 1987

The National Science Foundation recognizes the "greenhouse effect" as an important national and international scientific and societal issue that must be addressed in a scientifically rigorous and comprehensive manner. The long-term trend in atmospheric carbon dioxide and other important trace gases and recent data suggesting significant changes in the earth's ozone layer have led to a growing awareness of the potential for changes in the global climate. Changes in the global environment, of which the greenhouse warming phenomenon is but one example, can precipitate significant economic, social, and public policy issues which the United States must be prepared to address. An effective response to the impact of global changes requires a thorough investigation of the earth's climate and life support system and the interactions among the individual elements of this system.

Accordingly, NSF provides significant grant support to the academic community involved in research related to the greenhouse effect and global climate change. NSF is a major contributor of federal funds for the support of greenhouse effects research. During FY 1987, NSF funding of research in this area amounted to $8,121,000, which was distributed among the following categories:

I. Measurements and Observations: Measurement of the carbon dioxide content of the atmosphere and its seasonal and interannual variation; measurements of all aspects of the carbon cycle as well as other greenhouse gases such as methane and nitrous oxides;

II. Modeling: Research using regional and global numerical models to understand the greenhouse effects and feedback processes in the climate system;

III. Vegetation Response: Studies of the response of the large scale vegetative cover to increasing levels of carbon dioxide and other greenhouse gases in the atmosphere, and feedbacks to the climate system;

IV. Indirect Effects on the Atmosphere: Studies of the temporal variability of the greenhouse gases through the geologic epochs, and their possible role in determining the state of the climate system.

Results of recent research indicate that biotic and nonbiotic components of the earth system are closely interrelated, and that human impact on the geosphere and biosphere may in some cases approach the impact of natural processes. It is important to proceed with an integrated cohesive Global Change Program to define the processes involved and their interrelationships. This will improve our ability to predict the global effects of changes such as those recently observed in the ozone layer and in concentrations of greenhouse gases.

Improved scientific capabilities and technological advances have made it possible to conduct this program now. Modeling capabilities in the geosciences are very good; observational capabilities have improved dramatically in the past decade; and, perhaps most importantly, many of the best U.S. scientists are eager and willing to investigate the manageable scientific problems associated with global change. Conducting a Global Change Program would expand our ability to understand changes in the earth system and to predict their impact. This also would enhance our ability to respond to these changes.

The Global Change Program is a comprehensive research program to understand better the changes in the earth's environment. Because of the scope of this program, no one agency can be responsible for the whole program, and many Federal agencies have expertise and missions that can contribute to the objectives of the Program.

NSF has responded to pressing global concerns by selectively and aggressively proposing a major agency-wide, cross-agency, multidisciplinary thrust called Global Geosciences in the FY 1987 and FY 1988 budgets to Congress.

The central goal of Global Geosciences is:

> To understand how the planet Earth functions as a system of interrelated processes and to establish major cause and effect relationships within and among the climate system, biogeochemical cycles, and tectonic activity operating within the atmosphere, oceans, biosphere, and solid earth.

The rationale for Global Geosciences' focus on global interactive sciences is threefold:

1. Long-term observations of our environment reveal natural and anthropogenic changes in the delicate earth system, some of which may be irreversible and currently have an unpredictable effect. It is imperative to understand the processes contributing to such environmental changes as increasing carbon dioxide and other greenhouse gases, stratospheric ozone depletion, deforestation, and desertification.

2. At the same time, technological advances enable us to measure and observe the Earth better than ever before. Satellites can now monitor certain critical biological, chemical, geological and physical parameters over large spatial scales. However, dedicated research satellites will not be operational for several years. In-situ measurements using high-speed, high-precision instruments provide critical field information, and will provide a future necessary complement to validate and calibrate the cruder but larger scale satellite data.

   Combining remote sensing capabilities with in-situ observations offers the potential for the acquisition of global data sets, and thus make possible for the first time simultaneous pictures of global processes such as ocean and atmospheric circulation, and distribution and densities of ocean and terrestrial biota.

3. State-of-the-art scientific computing allows for computer communications, data management and processing, networking, and sophisticated modeling of earth systems.

Global Geosciences began in FY 1987 and has been expanded in the FY 1988 Budget request to Congress to include the following program elements:

Coupling, Energetics, and Dynamics of
    Atmospheric Regions (CEDAR)
Global Tropospheric Chemistry Program (GTCP)
Global Ocean Flux Study (GOFS)
World Ocean Circulation Experiment (WOCE)
Tropical Ocean/Global Atmosphere (TOGA)
Global Ecosystem Dynamics
Paleoclimate Studies from Ice Sheets
Ocean Ridge Crest Processes
Solid Earth Studies

A brief description of each element of NSF's Global Geosciences Program follows:

Global Tropospheric Chemistry: Addresses processes by which substances of natural or anthropogenic origin enter the atmosphere, are transformed, transported by winds, and ultimately removed. Studies distribution and interactions of compounds in the troposphere.

WOCE: (World Ocean Circulation Experiment; NSF lead, with NASA and NOAA.) Studies the general circulation of the global ocean, its average state, and its variability and heat flux in an effort to better predict oceanic forcing, response and feedback to long-term changes in the atmosphere. NSF will fund in-situ oceanographic field programs and model development through the next few years. In the 1991-92 timeframe NASA has launch plans for TOPEX and the NASA Scatterometer instrument on the Navy's NROSS. At this time NSF will intensify its field programs to coordinate specifically with NASA/NAVY ocean satellites, calibrate and validate the satellite data, and use the data to refine the models.

TOGA: (Tropical Oceans and Global Atmosphere; NOAA lead). Will investigate the interannual variability of the tropical ocean-global atmosphere system, its predictability and interactions. TOGA will also develop predictive models. NSF funds the basic physical oceanography and atmospheric process research that contribute to this program, as well as the modelling efforts. WOCE and TOGA will contribute substantially to each other.

Global Ocean Flux Study: Identifies and quantifies the physical, chemical and biological processes controlling large-scale biogeochemical cycling and fluxes in the open and coastal oceans and at their boundaries with the atmosphere and solid earth. Seeks to understand sources, production, and fate of biogenic materials in the sea well enough to predict their influence on perturbations significant to the global environment. This program will be greatly enhanced by a yet-to-be-funded satellite that images ocean color.

Global Ecosystem Dynamics: Uses long-term, large-scale observations to examine the role of the terrestrial freshwater biosphere in an global earth system. Studies the structure and function of ecosystems and their interaction with the atmosphere and hydrosphere. Many of the activities of this subcomponent are organized by the NSF Directorate for Biological and Behavioral Sciences.

Ridge Crest Processes: Studies the driving mechanisms of plate tectonics, the volcanic, tectonic, and hydrothermal processes at ridge crests, and their geological, chemical, and biological effects. Research will use modern acoustic imaging systems and a long-term instrumented seafloor "laboratory."

Solid Earth Dynamics: Studies images of the earth's interior using a new global seismic network, thereby contributing to the understanding of earthquake mechanisms, convection in the earth's interior, and the dynamics of plate motion. Global

Positioning Satellite (GPS) observations will contribute to our understanding of earthquake processes, plate motions, rifting, mountain building, volcanic behavior, and sea level fluctuations.

Paleoclimates from Ice Sheets: Uses cores from ice sheets that preserve and record annual precipitation and atmospheric temperature and composition, yielding hundreds of thousands of years of paleoclimatic information. This international, bipolar program will examine past climate information, ice sheet dynamics and geophysical events such as volcanic eruptions and meteor showers.

CEDAR: (Coupling, Energetics and Dynamics of Atmospheric Regions) studies the latitudinal and vertical coupling between the upper and middle atmospheric regions using optical and radio instruments in coordinated field campaigns.

In FY 1989 and beyond, NSF hopes to fund studies of climate change on both shorter and longer time scales, using all the natural earth archives, such as tree rings, ice cores, deep sea cores, and sedimentary rocks. Other research will study how marine populations grow to maturity and are distributed in the oceans. The plan also provides for studies of the interfaces between ocean and terrestrial environments. Research in the polar regions is an integral part of global geosciences.

The need for careful planning of data management and state-of-the-art modeling and networking are essential to the success of Global Geosciences. The science agencies have established an Ad Hoc Interagency Working Group on Data Management for Global Change, to address such issues as standardization, distribution, and accessibility of global data sets.

Global Geosciences is the product of a complex planning process that builds upon the science plans and priorities of external advisory bodies such as the boards of the National Academy of Sciences and NSF advisory committees. These disciplinary groups represent the science community, and help develop NSF long range plans for earth sciences research. NSF has integrated these plans into a comprehensive multi-disciplinary five-year plan for the Global Geosciences Program. This program remains the highest priority activity and a major focus within the NSF Geosciences Directorate.

APPENDIX

RESPONSES TO ADDITIONAL COMMITTEE QUESTIONS

RESPONSE OF DR. JOHN FIROR
TO QUESTIONS FROM THE SENATE COMMITTEE ON
ENERGY AND NATURAL RESOURCES
30 November 1987

1. Should we focus preventive actions on trace gases rather than CO2? Are trace gases inherently easier to reduce than CO2?

I assume that in these two questions "trace gases" is used to mean important infrared absorbing gases other than carbon dioxide. Given this assumption I respond "No" to both questions. I believe that our priorities for action should be in the following order:

1) Carbon dioxide/fossil fuels.

Carbon dioxide from fossil fuel use is the largest contributor to the projected global warming. Reductions in fossil fuel use are not only technologically possible today but such reductions would have benefits far beyond slowing the climate change. These two facts indicate that reductions in carbon dioxide emissions should be the prime focus for preventive actions.

The rapid increase in global use of fossil fuel developed in times of low fossil fuel prices and an apparent belief that, for each country, energy use and GNP were tightly related. The large price fluctuations of petroleum in recent years taught us that GNP can grow while energy use remains constant and that many improvements in energy-use efficiency are readily available. The most recent studies of future energy systems indicate that the technology already exists for major additional gains in end-use efficiency and that many of these technologies are much less expensive than high-tech alternative energy sources, such as nuclear energy, or any proposed system of gathering and sequestering carbon dioxide emissions. In addition, any shifts that can be created away from coal burning and towards natural gas use can reduce carbon dioxide emissions for the same amount of heat generated.

Shifts away from coal and reductions in total fossil fuel use have other benefits, including the reduction of acid rain and urban air pollution and improving the U.S. trade deficit. Reductions in electricity demand through efficient energy use can directly reduce sulfur oxide and nitrogen oxide emissions from power plants, making easier the long term solution of the acid rain problem. Also, sulfur and carbon dioxide are both reduced by shifts from coal to natural gas. Smog, ozone, carbon monoxide, and particulates that plague some large American cities today are all related to the urban use of fossil fuel, and lower fuel use would make the alleviation of these problems easier. Finally, the nation's balance-of-payments and debt problems are made worse by the large expenditures for foreign oil. Reduction in these imports would aid in dealing with these difficult economic issues.

International agreement will of course be needed for the long-term stabilization of the amount of carbon dioxide in the atmosphere. But the United States should begin its steps promptly, and if necessary unilaterally, for two reasons. First, the U.S. is the largest user of fossil fuel in the world, and major reductions on our part will necessarily be part of any global plan. Second, Third World countries would be unlikely to join in any agreement in which the developed countries with high fuel use do not lead the way.

2) Halocarbons. Certain industrial chemicals containing fluorine, chlorine, and bromine are powerful infrared absorbers and are growing very rapidly in the atmosphere. Recently, national representatives negotiated a treaty designed to limit production of the chemicals in this group that threaten the stratospheric ozone layer. These same gases enhance climate heating, so U.S. action to ratify and enforce this agreement is appropriate both to protect the ozone layer and to slow climate heating. However, the slow-down in production envisioned in the draft treaty may not be sufficient to prevent major damage to the stratosphere. Similarly, continued emission of these gases will add to the accumulated climate heating. Therefore consideration should be given to invoking those treaty terms which allow for reconsideration of the schedule of production phase-out.

3) Methane. Despite the increasing importance of methane as a climate heating gas, we do not yet fully understand its sources, nor how to control it. Thus the first priority is more study of its sources and possible control techniques. The same is true for nitrous oxide.

4) Other gases. There are a number of other gases, mostly industrial chemicals, that could contribute to the climate heating and which need to be monitored. For some, more study is needed; for others, greater recycling rather than release to the atmosphere will be required.

2. To what extent will the accumulation of greenhouse gases be reversible if emissions subside?

This question can be answered with some certainty for the major halocarbons - CFC-11 and CFC-12 - since only stratospheric photolysis removes them and we can estimate this rate of removal from production data and measurements of atmospheric concentrations. We can estimate that in a hundred year's time, if emissions of these CFC's could be completely stopped today, their concentrations would be about half their present level. Given the amounts of CFC's that have been manufactured but not yet released to the atmosphere, and the relatively slow phase-down envisioned in the proposed treaty, the concentrations of these gases are likely to continue to increase for decades to come.

For complex reasons we are less certain about the net removal rate of carbon dioxide. But with reasonable assumptions, we can calculate that even with a prompt reduction of global fossil fuel use to two-thirds its current value, the amount of carbon dioxide in the air would continue to increase to about 450 or 500 parts per million, well above the current value of about 350 ppm. A hypothetical instantaneous reduction of fossil fuel use to one-half the current rate should stabilize the carbon dioxide content of the air at about its current value. It is difficult to imagine any possible set of near term actions that would reduce CO2 in the air below today's amount.

The lifetime of methane in the atmosphere is much shorter than the other gases discussed here. If human-induced emissions could be reduced to zero, the concentration should return to its preindustrial value in a few decades. The relationship of methane emissions to agricultural activities suggests, however, that such a reduction in emissions is very unlikely.

3. Are existing scientific research programs adequate? If not, what specific changes would you like to see? What areas of Global Climate research need more funding?

All parts of the global climate research programs need reliable funding over a number of years to allow wise research program design. I believe that some parts of the research program need enhancement.

Three characteristics of climate research make it a difficult, as well as challenging, field of study. First, answers frequently come from surprising places. Who would have guessed that cores brought up from the floor of the Indian Ocean, pollen grains from peat bogs in Minnesota, or improvements in radiocarbon dating of archeological material would have provided information essential to understanding past climates and the workings of the current climate system? This characteristic indicates that a healthy climate research program must be embedded in a vigorous study of geophysics and of the biosphere.

Second, it has become clear that the interactions among the air, the ocean, the ice caps, the hydrological systems, and ecology are fundamental to the workings of the climate. This fact requires that, much more than in the past, the nation's research effort include a strong interdiscliplinary component, focusing attention on the nature of these interactions and their long term influence on the conditions of the air and ocean.

Finally, for the first time in the history of the earth, human activities have become a major force in the global climate. This troublesome fact must be studied and understood if reliable outlooks about the future of the climate are to be produced.

In my judgment, the areas most needing enhancement are in the interaction of ecosystems with the atmosphere and in the interaction of people with the atmosphere. The first of these requires a much enhanced ability to measure trace amounts of substances flowing into and out of particular ecosystems, both on land and in the ocean, and a rapid improvement in the ability to model, numerically, ecosystems and their interaction with their environment. The interaction of people with climate involves seeking answers to many questions that may require new methods, new interactions among disciplines, and the creation of new research groups for their resolution. Such questions include: In what manner will climate change first affect society? What will be the response of society to these impacts? What are the tools available to society to manage the emissions of infrared absorbing gases and to what extent can those tools be used?

Progress in both of these areas will be hastened by an improved ability to specify how the climate change will manifest itself in each region on earth. Regionally specific models will likely emerge from enhanced support for the major climate modelling groups so that they can proceed to higher resolution representations of the climate. This work needs to be combined with field and modelling studies of important smaller-scale phenomena that influence climate and much enhanced attention to the interaction of the atmosphere with regional scale surface phenomena such as occur in hydrology, ecosystems, oceans and ice.

4. Your testimony implies that a strong consensus exists that there will be an average global warming, but that substantial uncertainty remains concerning effects in specific regions. What level of certainty can you attach to predictions of sea level rises in contrast to more regional specific predictions?

Sea level rise, being a global average phenomenon, can be projected in the short run with somewhat more certainty than can the future climate at a specific location. This conclusion is supported by the fact that the sea has risen about 10 cm in this century in parallel with the one-half degree global warming.

On a longer time scale, if the warming is allowed to proceed at a rapid rate, we may be facing surprises in both the nature of regional heating and the rate of sea level rise. The regional heating pattern could change suddenly if the ocean circulations shift as a result of the atmospheric changes, and the sea level could respond to major changes in Antarctic ice sheets.

5. Does the Department of Energy share your view that we can place a strong degree of confidence in the climate models that predict a global warming?

Respected individual scientists and groups of scientists at DOE-supported laboratories are among those contributing to knowledge of carbon emissions, to improvements in climate models, and hence to the emerging consensus on the heating of the climate. However DOE's research priorities do not yet indicate, to an observer outside the agency, much continuing interest in or concern for preparing the country to respond to projected climate heating. For example, DOE's research program on climate heating is less comprehensive and coordinated than it was a decade ago; the work of the Solar Energy Research Institute has been reduced, and its study and demonstration projects for passive solar houses, designed to reduce energy demand, have been eliminated; and while DOE has research programs for increasing the usefulness of coal, it has none that I am aware of for decreasing total coal use.

Answers to Questions Submitted to the National Oceanic and Atmospheric Administration in Followup to the November 9, 1987 Hearing on Global Change before the Senate Committee on Energy and Natural Resources

QUESTION 2:

Do you foresee dramatic changes in precipitation patterns over North America? What are the steps that can be taken to prepare for aberration in normal rainfall?

ANSWER:

Averaged over the entire North American continent, the rates of both precipitation and evaporation increase in response to the increase of greenhouse gases in the atmosphere. Although current models are useful for identifying only very broad scale features of precipitation change, they indicate that the greenhouse gas-induced change of precipitation varies from one geographical region to another. In a warm climate with higher concentrations of greenhouse gases, warm, moisture-rich air can penetrate into higher latitudes. Thus precipitation is expected to increase much more than evaporation in these latitudes, resulting in a marked increase in runoff over Northern Canada. In the northern half of the middle latitude rainbelt, the increase of precipitation is also expected to substantially exceed that of evaporation. However, in the southern half of the rainbelt, precipitation hardly increases (or is reduced) but evaporation increases significantly. This contributes to a reduction of soil wetness over the mid-continental region of the USA located under the southern half of the rainbelt in summer. (See references (1,2) in the text of my statement for further discussion of this topic.)

These results suggest that the availability of water increases in one season (or region) but is reduced in another season

(or region). Obviously, these changes could have a major implication on the issue of water management.

QUESTION 3:

You have stated in your testimony that changes in soil wetness may have profound agricultural and other implications. Could you elaborate on these implications?

ANSWER:

As I noted in my testimony, the results obtained from the Geophysical Fluid Dynamics Laboratory/NOAA and some other institutions suggest that soil wetness may be significantly altered in response to future increases of greenhouse gases in the atmosphere. When the warming due to the doubling of greenhouse forcing is fully realized possibly during the latter half of the next century, it is expected that the snowmelt season with wet soil will arrive earlier by about one month and the summer period with very dry soil is extended by 1 to 1.5 months.

As I stated in my testimony, I suspect that these large scale changes in soil wetness and water availability may have profound agricultural and hydrological implications, although I am not an expert on these issues.

QUESTION 4:

The hearings outlined the various factors that contribute to the greenhouse effect, yet little mention was made by the scientists of the ocean's role in regulating CO_2. Do the oceans also act as a sink for any of the trace gases, or are their absorptive properties restricted to CO_2?

ANSWER:

The oceans are very inefficient sinks for fluorocarbons and nitrous oxide because of the extremely low solubility of these gases.

QUESTION 5:

Limitations in the record of global average precipitation, particularly over the ocean, make short-term identification of any CO_2-induced signal in the record very difficult. What are some of the methods models use to distinguish CO_2-induced changes in precipitation over long-term fluctuations in rainfall due to natural causes?

ANSWER:

Difficulties arise in detecting the changes in precipitation induced by the increase of greenhouse gases due to the large natural fluctuations in precipitation that occur from year to year. Since the change in climate due to increased greenhouse gases is gradual, a number of years may be required before the changes in precipitation are large enough to be distinguished from the "background noise" of natural climate variability. A similar difficulty exists in interpreting results from climate models, since these models simulate precipitation variability similar to that which occurs in nature. In both models and nature we often use standard tests of statistical significance (student's t-test, trend analysis) to distinguish the changes induced by greenhouse gases from the natural fluctuations.

QUESTION 6:

What are the possible feedback mechanisms that may serve to amplify or diminish the changes in precipitation levels? How do clouds act as a feedback mechanism for precipitation levels?

ANSWER:

Although major uncertainty remains, our latest findings indicate that the cloud feedback process enhances the greenhouse gas-induced warming of the model climate. As noted already, such a warming of climate is accompanied by an intensification of the global hydrologic cycle (i.e., increases in global mean rates of both evaporation and precipitation). Therefore, it is probable that the cloud feedback process enhances not only the warming but also the intensification of the global hydrologic cycle resulting from an increase of greenhouse gases.

In a regional scale, the cloud feedback process can also exert substantial influence upon the hydrological process over a continent. When soil moisture is reduced, a larger fraction of radiation energy absorbed by the continental surface is ventilated through the upward flux of sensible heat rather than through evaporation. Accordingly, the temperature of the continental surface and overlying layer increases resulting in a general reduction in relative humidity and precipitation in the lower troposphere of the model. Accompanying a reduction in relative humidity is a reduction in total cloud amount, causing an increase in solar energy reaching the continental surface. Thus, the radiation energy absorbed by the continental surface also increases, raising the rate of potential evaporation. Both the decrease in precipitation and the increase in potential evaporation mentioned above further reduce soil moisture during the summer season. In summary, the cloud radiation-hydrology interaction acts as a positive feedback process which enhances drought in summer. (See references (1,2) in the text of my statement for further discussion of this topic.)

QUESTIONS FOR DR. BLAKE

1. On page four of your testimony presented before the Committee you stated "...infrared radiation of the wavelengths, which can be absorbed by CO2 vibrations...is nearly saturated. Increasing the concentration to 351 ppmv will increase the probability of absorption a little, but it is hard to increase the total absorption very much if it is already 99.9%"

Does this statement mean that CO2 levels in the atmosphere have reached a saturation point? If yes, does it matter if the world continues to pump CO2 into the atmosphere? If not, could you explain the statement as it reads on page four of your testimony?

2. Is there a methane feedback loop that leads to more methane as temperatures increase?

3. Will you elaborate on the function of the hydroxyl radical and its role as a cleansing agent for greenhouse trace gases in the atmosphere. What effect will rising levels of CO2 have on the ability of the hydroxyl radical to act effectively?

4. What levels of funding do you feel are necessary to study trace gases? Would you like to see more interagency coordination on trace gas research?

5. Can anything be done to slow the emission of methane into the atmosphere? What would be the costs of such procedures?

Statement by Dr. Donald Blake
University of California, Irvine
Department of Chemistry

1. The statement I made in my testimony concerning the saturation of carbon dioxide vibrations was used to illustrate the importance of very small increases in other trace gases with respect to global warming. The CO_2 infrared absorption band at 15 microns contributes significantly to the energy budget of the atmosphere and this is the absorption band that is essentially saturated. However, there are other less effective absorptions and isotopic absorption bands that are not saturated and it is these bands that will contribute to increased global warming as atmospheric carbon dioxide levels increase.

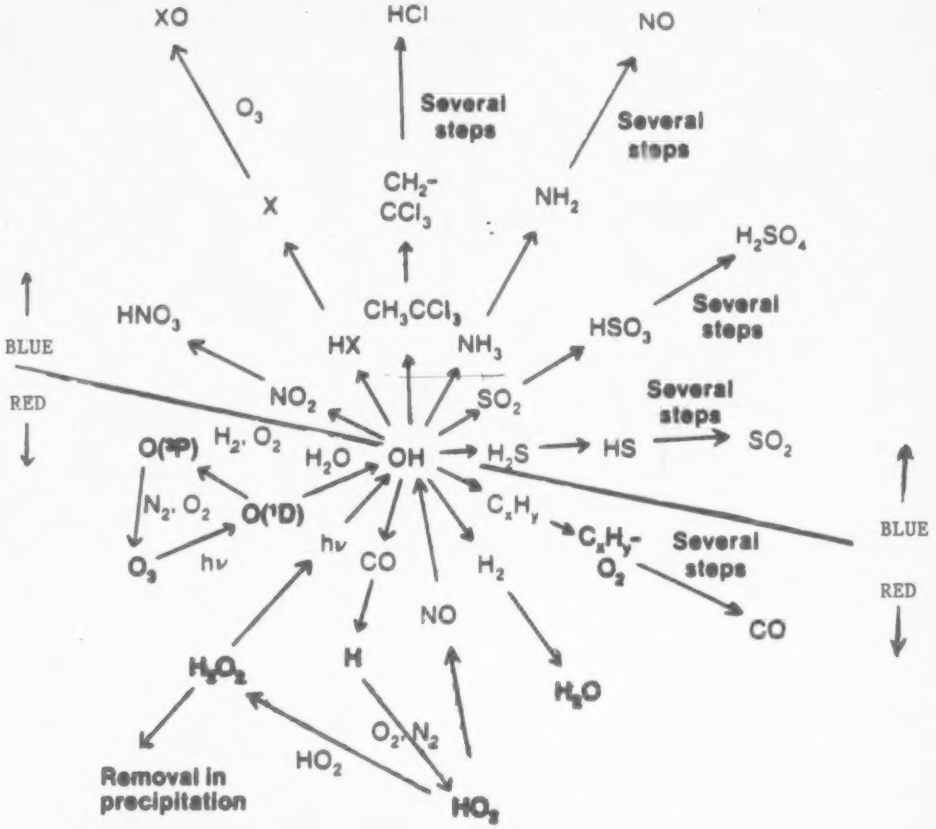
2. The sources of atmospheric methane are varying and numerous. Two of the major sources are rice paddy fields and swamps. These two sources are responsible for as much as 40% of all methane emissions into the atmosphere. Studies involving some of these ecosystems have yielded results showing a strong temperature dependence. As temperatures increase so does methane emissions into the atmosphere. This increase in atmospheric methane will in turn cause increased absorption of outgoing terrestrial radiation thereby increasing global warming by a small amount. Not only is there a positive methane feedback with increasing temperatures, but any increase in the concentration of radiatively important trace gases will affect the methane production from these ecosystems.

3. There are numerous ways in which a gas emitted into the atmosphere can be removed. Perhaps the most obvious one would be that associated with rainout. However, many gases are not water soluble and thus are unaffected by precipitation. A second method is photolysis, a process involving the absorption of radiation sufficiently high in energy so as to rupture a bond within the molecule. Depending upon the properties of the gas in question, this will occur at different altitudes within the atmosphere. A third removal process involves chemical reactions.

The main atmospheric specie responsible for removal of trace gases from the atmosphere is hydroxyl radical (HO). I have included a simplified diagram depicting the role of HO in the atmosphere. The hydroxyl radical is responsible for regulating the levels of hundreds of trace gases in the atmosphere.

The two species most responsible for regulating the atmospheric hydroxyl radical concentration are carbon monoxide and methane. Methane is increasing an the atmosphere at about 1% per year. Carbon monoxide exhibits large seasonal changes in concentration, thus, small increases in its average world-wide concentration are difficult identify, but some studies indicate an increase of about 1% per year also. Therefore, as methane and possibly carbon monoxide increase, HO will decrease by a corresponding amount. A lower HO concentration will allow all species dependent on HO removal to remain in the atmosphere for a longer time. As the atmospheric residence time of these gases increases each compound has more time to participate in trapping outgoing terrestrial radiation, and for some species to diffuse up to the stratosphere where they will affect ozone levels.

Photochemistry of OH radical controls trace gas concentration


XO
HCl
NO
O_3
Several steps
Several steps
X
CH_2-CCl_3
NH_2
H_2SO_4
BLUE
RED
HNO_3
CH_3CCl_3
HX
NH_3
HSO_3
Several steps
Several steps
NO_2
SO_2
$O(^3P)$
H_2, O_2
H_2O
OH
H_2S
HS
SO_2
N_2, O_2
$O(^1D)$
C_xH_y
C_xH_y-O_2
Several steps
BLUE
RED
O_3
$h\nu$
$h\nu$
CO
H_2
NO
CO
H_2O_2
H
H_2O
O_2, N_2
HO_2
Removal in precipitation
HO_2

The photochemistry of the free hydroxyl radical controls the rate at which many trace gases are oxidized and removed from the atmosphere. Processes that are of primary importance in controlling the concentration of OH in the troposphere are indicated in red in the schematic diagram; those that have a negligible effect on OH levels but are important because they control the concentrations of the associated reactants and products are indicated in blue. Circles indicate reservoirs of species in the atmosphere: arrows indicate reactions that convert one species to another, with the reactant or photon needed for each reaction indicated along each arrow. Multistep reactions actually consist of two or more sequential elementary reactions. HX = HCl, HBr, HI, or HF. C_xH_y denotes hydrocarbons

Department of Energy
Washington, DC 20585

December 15, 1987

Honorable J. Bennett Johnston
Chairman
Committee on Energy and Natural
  Resources
United States Senate
Washington, D.C. 20510

Dear Mr. Chairman:

On November 10, 1987, Dr. James F. Decker, Acting Director, Office of Energy Research, appeared before your committee to discuss Global Climate Change and the Greenhouse effect.

Following that hearing, you submitted written questions for our response to supplement the record. Enclosed are the answers to those questions.

If you have any questions, please have your staff call Mark Waggoner on 586-4277. He will be happy to assist.

Sincerely,

J. Thomas Todd
for Robert G. Rabben
Assistant General Counsel
  for Legislation

Enclosures

Celebrating the U.S. Constitution Bicentennial — 1787-1987

Q.1. Does DOE currently have any studies underway to determine what policy choices are available to slow the buildup of greenhouse gases and eventually stabilize the concentration of these gases in the atmosphere?

A. The Department is studying the effects that changing energy technologies may have on the future reduction of atmospheric carbon dioxide (CO_2) buildup. Studies completed include a) an analysis of a variety of physical, chemical and biological processes for controlling the concentration of CO_2 in the atmosphere, and b) a systematic study on the removal, recovery and disposal of CO_2 from fossil fuel-burning power plants in the U.S. A preliminary study, the purpose of which was to estimate the potential for reduction in buildup of atmospheric CO_2 by the year 2050, also focused on the anticipated effectiveness of future energy end-uses and various alternative electricity-generation technologies of the global energy system. This study showed potential savings amounting to a 57% reduction in the demand for fossil fuel in 2050, compared with the same demand when met using the technologies and energy efficiencies of the mid-1970s.

The purpose of our current studies is to obtain a better understanding of how energy is used for specific energy services in countries identified as major and emerging CO_2 emitters. This is done by identifying and characterizing the energy technology improvements of future energy systems that are expected to be used (or at least to be available for use) in these countries. This will lead to a meaningful ability to predict impacts and effects of various new and improved technologies on global CO_2 emissions, providing, thereby, a number of technology assessments and options on the basis of which policymakers may formulate future energy production and use plans.

Q.2. Will climate models ever be absolutely certain in their predictions of the effects of growing concentrations of greenhouse gases? Is absolute certainty in prediction required before the Department of Energy takes preventive or preparatory action? If not, has the Department considered what the appropriate level of "threshold" certainty is, i.e., a level of certainty in prediction that should trigger action on the part of the Department? If so, what is DOE's position?

A. We know that atmospheric carbon dioxide will rise in the future. We are reasonably certain that global temperatures will correspondingly rise and precipitation will increase. We believe that global sea level will probably also rise, although a drop in sea level is not out of the question. Reasonably certain projections of how these changes might affect our Nation's resources on a regional basis are needed before action can be recommended. We do not, and cannot, require absolute certainty in climate models as this would be an objective that would be impossible to achieve. What we do require is improved climate models that can provide reliable, regional projections of climate parameters that can then be used by resource analysts to generate integrated quantitative regional projections of the combined effects of increasing CO_2 and climate change on our resources. Without this level of detail, it would be premature to assign "threshold" values that would be used to trigger policy actions. The Department is currently active in conducting the research and developing the data and methodologies needed to provide this level of detail as rapidly as possible.

Q.3. How does the greenhouse problem effect DOE priorities with regard to regulations, conservation policies, energy research and development?

A. The greenhouse effect is one of several long-term concerns that are factored directly or indirectly into the ordering of Departmental priorities. To further assist us in this function, Frederick Koomanoff, the Director of our Carbon Dioxide Research Division, has made two presentations to the Energy Research Advisory Board (ERAB) on the CO_2 issue, the most recent being the November 4th meeting of the Board. Both presentations were designed to assure the expert advice we receive from ERAB includes a perspective on and due consideration of the greenhouse issue. Examples of its consideration in various program areas follow:

1. In the Magnetic Fusion Program Plan, the CO_2 issue was considered in developing the program schedule and strategy.

2. In our planning for the next generation of DOE research computing, the inclusion of supercomputing needs for climate modeling reflects our concern over the CO_2 issue.

3. While the priorities relative to DOE conservation policies are primarily driven by the Department's national energy security objectives to the extent that reduced energy needs also reduce fossil fuel use, they correspondingly, reduce CO_2 emissions. Renewable energy technologies such as solar thermal, photovoltaics, hydropower, wind and geothermal are energy sources that produce negligible amounts of CO_2.

Likewise, our fossil energy research programs contribute to both national energy security and the reduction of CO_2 emissions. Advanced energy technologies, such as the innovative clean coal technologies, have the potential for increasing fuel use efficiencies from 33-50%, potentially reducing the CO_2 emitted by an advanced-technology coal-fired plant, as compared to a conventional plant. Through direct communication between the staff of the Carbon Dioxide Research Division, and the Conservation and Fossil Energy programs, the greenhouse effect is implicitly, if not always explicitly, weighed in the decision-making process through which the various program priorities are established.

5. As to regulatory priorities related to the greenhouse gas issue, the Department supports the Montreal Protocol for the protection of the ozone layer. The Department supports the development of efficient domestic regulatory mechanisms for the implementation of the protocol and will be publicly commenting on EPA's proposed regulation with the objective of developing the most efficient and effective regulatory forms.

In summary, the Department considers the greenhouse issue in formulating both its energy research policy and its national energy security policy.

Q.4. Please state clearly the effect that clean coal technologies will have on CO_2 and trace greenhouse gas emissions relative to conventional coal-fired generation.

A. Clean coal technologies are a broad set of new technologies which are intended to increase the fuel efficiency and environmental acceptability of expanded coal use in both traditional and nontraditional sectors. The set includes a number of technologies which will lower emissions of sulfur oxides and nitrogen oxides per unit of energy generated, relative to conventional coal fired generation, by cleanup of fuels and/or emissions before, during, or after use. It also includes technologies which will increase the efficiency of energy generation from coal, thereby decreasing the amount of fuel required to produce a given energy output and, accordingly, the amounts of carbon dioxide, and other pollutants (e.g., sulfur oxides and nitrogen oxides) that would otherwise have been produced for that level of energy generation. For example, conventional coal-fired generation has a fuel efficiency of only about 33-35 percent, while innovative clean coal technologies have the potential for fuel efficiencies of 40-50 percent. All other things remaining equal, that could translate into as much as a 50% decrease in the amount of carbon dioxide which would be produced by a coal-fired facility, if it utilizes an innovative clean coal technology with a fuel efficiency of 50% rather than a conventional technology with a fuel efficiency of 33%.

It should be particularly noted that the innovative clean coal technologies with emissions-reduction capacity exhibit improved performance in the removal or control of nitrogen oxides and sulfur oxides as compared to conventional emissions-control technologies. In particular, since nitrous oxide (N_2O), one of the trace gases considered in connection with global climate change potential, is a nitrogen oxide capable of being reduced or removed by advanced equipment or systems, these technologies can also be expected to lead to reduced N_2O emissions.

In summary, the use of innovative clean coal technologies is expected to have a beneficial effect on the levels of the emissions of interest, as compared to the use of conventional coal-fired generation.

Q.5. Given the fact that scientists claim we may already be committing ourselves to a significant and irreversible global warming through our use of fossil fuels, why does the Department advocate waiting to act until more is known about global warming?

Your testimony implies the existence of a strong consensus regarding global warming, but that substantial uncertainty remains concerning specific regional effects. What level of certainty (qualitatively or or quantitatively) can you attach to the global effects of climate change (sea level rise, disruptive changes in precipitation, etc.) in contrast to more regional specific predictions?

A. The Department advocates further research, rather than immediate action, in this area because the data are lacking to resolve the differences between the model estimates of greenhouse-induced warming and observed warming. We know that, over the last century, the globe has warmed by about 0.5^oC (0.9^oF). For the same period of time, however, the models estimate that the warming attributable to the greenhouse effect should have been about 1^oC (1.8^oF). Several scientists believe that this discrepancy has been due to the fact that the oceans, with their large heat-retention capacity, have stored the heat and delayed the warming. This would mean that the warming is inevitable. Nonetheless, there are other possible reasons for the difference: the models could be overestimating the warming by a factor of two because of the lack of, or the crude formulation of, data on, and models of, an important climate process. For example, clouds can act to enhance or moderate the warming, and several scientists have estimated that moderation by clouds could have been by as much as a factor of two, thus cancelling half the warming. Thus, the ocean and the cloud data and models are insufficient, at the present time, to resolve the differences.

Further, as referred to in the second part of your question, substantial uncertainties remain concerning regional climate changes. For example, at the regional level, climate models and observations can yield results that differ by 5°C (9°F) or more, and, in comparing model runs for two times present levels of CO_2, regions can have opposite signs regarding precipitation change.

Without a reasonable knowledge of the interrelationship between climate and CO_2 changes and the nature and extent of the impact of these changes on our Nation's resources and their use by and interaction with society, we would be simply taking action on the premise that the changes and their effects are "bad" and that the selected actions will "fix" the problem. Therefore, we currently are working toward climate model improvement to provide reliable projections of climate parameters, particularly on a regional basis, which can be used by resource analysts in generating integrated quantitative projections that can be used in assessing climate change impacts on our resources and in determining what kind of actions, if any, need to be taken in amelioration thereof.

Q.6. What funding does the Department currently receive to study the relationship of trace gases to the greenhouse effect? In light of new evidence pointing toward the contribution of trace gases to a global warming, will DOE be directing additional funds toward research in this area? If so, how much of the budget will be directed toward future trace gas research?

A. The Department's budget for CO_2 research was $12,396,000 in fiscal year 1986 and $13,044,000 in fiscal year 1987; our planned spending is $13,976,000 for fiscal year 1988, as of this date. The Department's focus is on trace gases (i.e., atmospheric CO_2) associated with energy production. Based on an annual survey we make as lead agency for the coordination of carbon dioxide-related research, the Federal effort on this research was approximately $28,000,000 in fiscal year 1987.

Due to recent scientific findings and growing national and international interest, DOE is reviewing its funding of this extremely vital research area.

Q.7. Many scientific experts suggest that large reductions in the output of CO_2 could be achieved through the implementation of energy conservation measures that would be not only better for the atmosphere, but economical as well.

What conservation measures and policies is the Department currently advocating? What are the sums that are currently being spent on energy conservation programs? Could you outline any future plans that DOE may have to explore conservation programs further?

A. DOE's conservation programs involve technologies, processes, and practices that inherently reduce CO_2 emissions. To this end, our policy is to support particularly R&D that increases the efficiency of fuel-using processes, reduces energy demands, or otherwise ameliorates emissions impacts by removing CO_2 from the ambient environment. Examples of DOE activities of these types follow:

1. CO_2 emissions from fossil fuel use can be reduced by improving combustion efficiency and by substituting nonfossil energy forms, e.g., solar, tidal, etc. The Department has current involvement at varying levels in each of these areas.

2. Enhanced oil recovery (EOR) is a use for CO_2 which will also store CO_2: CO_2 is injected in deep oil fields to promote additional recovery after initial production tapers off (which would leave perhaps 70 percent of the oil unrecovered). Approximately half of the injected CO_2 is released with the EOR oil; the other half remains in the deep oil field rock/sand formation thus reducing atmospheric CO_2. Large quantities of CO_2 exceeding the amounts of traditional sources will be required for future EOR by CO_2 injection. Therefore, new technologies to produce pure CO_2 will be required.

> To aid in meeting this need, DOE has developed a process at Argonne National Laboratory (ANL) to convert large industrial and power furnaces into generators of relatively pure CO_2 which can be transported by in-place pipelines to oil fields. The profitability is a function primarily of oil prices and pipeline distances; about $26 a barrel minimum and perhaps 300 miles maximum distance to the oil field. Not only is half of the combustion CO_2 prevented from entering the atmosphere, but the acid rain precursors, sulfur oxide and nitrogen oxide (SO_X and NO_X), are also prevented from entering. This process has been modeled extensively and field tested. (A western power-generating utility has shared in the cost of one of the tests and an eastern food processing company is interested in developing it in order to produce food grade CO_2. While the latter use would not diminish total CO_2, it provides industry support for the technology.) The process has, thus, been brought to the point prior to commercialization, and industry is being made aware of its potential benefits. Accordingly, no further DOE-sponsored R&D for this process is planned.

The Department conducts a broad based program of conservation R&D of technologies for all sectors of the economy, including buildings, industry, transportation, and utilities. The FY 1987 appropriation for conservation R&D is $162 million. The Department also conducts the Federal Energy Management Program, which supports energy conservation efforts within the Federal Government. In addition, over $3 billion from petroleum overcharge violation cases has been made available to the States for use in energy conservation efforts through the Department's State and Local Assistance Programs and the Low Income Home Energy Assistance Program at the Department of Health and Human Services.

The objective of DOE's Office of Conservation is to contribute to the goal of reducing atmospheric CO_2. This objective and the programs to achieve them are set forth in the Energy Conservation Multi-Year Plan (September 1987).

Q.8. To quote your statement Dr. Decker, "the Carbon Dioxide Research program was organized in 1978 to identify possible policy options for governmental action in response to change induced by atmospheric CO_2". In the past nine years what policies has the Research program devised for dealing with this problem?

Are there any mechanisms by which policy options formulated at the DOE Research program can be brought to the attention of those studying the Greenhouse Effect at other agencies?

A. The Department has recommended a policy of pursuing basic research into all major aspects of atmospheric-change potential, based on our series of State-of-the-Art reports which document the fact that the scientific base is not yet available from which to begin to formulate policy options.

The ultimate goal of the Carbon Dioxide Research Program conducted by the Department is the identification of policy options for governmental action in response to change induced by increasing atmospheric CO_2. The achievement of this goal requires a well designed, rigorous research program of considerable complexity and scope yielding data and models from which policy options can be formulated. The first requirement is that we develop a sound scientific base of knowledge about the cycling of CO_2 in the global environment and the potential effects on the climate and the biosphere of increasing atmospheric CO_2. We must then attempt to extend our current knowledge into the future by means of energy/emissions projections and climate model projections in order to estimate the combined effects of increasing atmospheric CO_2 and climate changes on our national resources and their potential resulting impacts on our interactions with societal institutions. While we are well along in our effort to establish the scientific base in the physical sciences, we have far to go in projecting the effects into the future to the degree that we can say with reasonable certainty what the combined effects on our resources might be.

Additionally, as demonstrated in answer No. 1, the Department is studying mechanisms which control CO_2 concentrations in the atmosphere and CO_2 reversal processes from fossil fuel-fired plants, in addition to studies of the implications of alternative energy demand and supply patterns. This is the type of information which informed policy will require. We believe, however, that attempts to articulate policies are premature, given the state of science and the paucity of policy studies.

Given the above situation, no mechanism has been developed or exists at this time for bringing policy options to the attention of those studying the greenhouse effect at other agencies, although the recently established OSTP Committee on Earth Sciences will provide a focal point for exchange and review of ongoing activities as it develops an effective and well-coordinated interagency global change effort. Part of this effort will be to ensure that this program will ultimately be supportive of policy formulation.

Q.9. The Department's testimony emphasized the international nature of the global warming problem and the magnitude of other countries' current and future emissions of greenhouse gases. What are the implications of this for U.S. policy? Must the United States act only in consort with other nations in attacking this problem, or is there some value in the U.S. taking unilateral steps to both reduce the problem and act as a catalyst in spurring a more cooperative effort?

A. The effect of increasing atmospheric CO_2 is on the global system and will affect all nations through regional climate and vegetation changes. While the U.S. contribution to the greenhouse effect is important, measures to prevent or slow the rate of global warming will require international solutions.

Unilateral control actions present at least two major problems. The first is the effectiveness of unilateral control actions. The U.S. contribution to any reduction in the emission of greenhouse gases would have limited effect on the rate of growth of these gases. However, if combined with reductions by other countries, the collective action could actually influence the rate of global temperature change.

The Department does not support unilateral domestic regulation of greenhouse gases. Since unilateral action on greenhouse gases may not have a perceptible effect on the rate of warming, it seems particularly ill advised to impose the costs in unemployment and monetary expenditures on the American people. Should the U.S. government determine that some control policy action is desirable, then the appropriate course of action is to seek international agreement on collective action which will be more effective and equitable.

There are, however, unilateral actions which the U.S. may find desirable. We must continue our leadership in the development of the science of the greenhouse effect and must continually share our knowledge with the international scientific community and solicit the cooperation of other nations in furthering the world's understanding of the problem. When we are reasonably certain what the combined effects of increasing atmospheric CO_2 and climate changes are on our nation's resources and societal institutions, then we will be in a position to recommend international actions. As we develop our precision in predicting regional impacts of climate change, we will also be able to evaluate mitigative policy responses which are a possible unilateral action which could be desirable. With our current ability to predict regional scale impacts, it is difficult to have confidence in evaluating possible mitigative actions. We must recognize that our nation's actions will lead the international response and minimize mitigative costs only if the policy options posed have a strong and credible scientific basis.

ANSWERS TO QUESTIONS REGARDING
Gordon J. MacDonald's Statement on
RELATIONSHIP BETWEEN CURRENT ENERGY TECHNOLOGIES AND THE GREENHOUSE EFFECT AND GLOBAL WARMING

Before the Committee on Energy and Natural Resources
United States Senate
November 10, 1987

Question 1:

In one of your earlier publications, you argue that SO_2 and NO_x are "sinks" for tropospheric ozone. Is this any basis for holding off on acid rain controls?

Answer:

1. The principal mechanisms for the conversion of sulfur dioxide to sulfuric acid involve oxidation by ozone and hydrogen peroxide in the liquid phase. The ambient concentration of hydrogen peroxide is dependent on the concentration of hydroxyl radical which, in turn, is dependent on the concentration of ozone. Large seasonal fluctuations in acid deposition--high in summer, lower in winter--are matched by similar seasonal fluctuations in ozone. The fact that there is essentially no corresponding seasonal variation in sulfur dioxide production supports the contention that sulfuric acid deposition is oxidant limited. Measures to limit ozone, including controls on volatile organic compounds and carbon monoxide which lead to ozone formation, will aid in lowering sulfuric acid deposition. In addition, sulfur dioxide acts as a

sink for ozone. In considering strategies to curb damage associated with acid deposition, I would give the highest priority to oxidant reduction measures. Oxidants themselves can cause forest damage that is sometimes attributed to acid deposition. Limitations on oxidants thus help both in controlling acid deposition and in decreasing direct damage. Much more costly measures to reduce sulfur emissions should be undertaken only after the effects of oxidant reductions have been determined. Oxidant reductions are required, in any case, by consideration of public health.

The issue of NO_x controls is even more complex. Nitrogen oxides participate in ozone formation, but it is the ratio of NO_2 to NO that determines ozone concentration, not the absolute concentration of NO_x. NO_2, unlike SO_2, is rapidly oxidized in the atmosphere to form nitric acid, which is responsible for about one-third the total acid deposition. Control of NO_x is likely to have a greater impact on acid deposition than controls on SO_2, but the technical difficulty and cost of NO_x controls are greater.

Question 2:

In response to a question from the Chairman, you outlined why it would be technically infeasible for clean coal technologies to reduce CO_2 emissions relative to conventional coal burning. Could you elaborate on your answer with reference to the physical and chemical processes involved?

Answer:

2. Technology for the removal of carbon dioxide from gases has been developed in the natural gas industry because carbon dioxide is often a natural constituent of natural gas that reduces its heat value. In principal, carbon dioxide could be removed from the combustion products and then disposed of by land or sea burial. The costs of such an undertaking are staggering due to the large mass of material involved, the relatively low concentration of CO_2 in the effluents and the wide distribution of the sources. About one-half of U.S. carbon dioxide emissions are from distributed sources such as automobiles and residences. The problems of controlling CO_2 emissions from such sources are different and more difficult than controlling emissions from central power plants.

   The principal means of removing CO_2 from flue gases are either chemical or cryogenic. Because the concentration of CO_2 in flue gas is low, 25% by weight, using chemically reactive systems is much less costly than attempting to freeze out the CO_2. Of the chemically reactive processes, alkanolamine-monoethanolamine (MEA) is particularly well-suited for low pressure flue gases as they emerge from a stack. CO_2 is chemically removed in solution during this process. The carbonate sludge can then be stripped out with steam to regenerate the MEA. An estimate of cost for removing 1,000 cubic feet of CO_2 a day from a 1,000 megawatt electrical plant burning 6,000 tons of 70% carbon coal is about $1.50. This figure corresponds to two cents per kilowatt hour, but does not include the MEA recovery system, cooling water recirculation pump (for disposal of the condensed process water), or the sulfur dioxide removal, which is essential for the process to work.

The most economical method of transport of carbon dioxide is by pipeline, with the gas at supercritical pressure, 1,100 pounds per square inch. Pipeline costs depend on total line length and on the terrain over which the pipeline passes from source to disposal site. Based on current experience, the cost for transporting 1,000 cubic feet of CO_2 from a 1,000 megawatt electric plant over 500 miles of average terrain would be about $1.00 and would add 1.3 cents to the cost of a kilowatt hour.

In addition to the cost of purification and transportation, there is the cost associated with injection of the gas into old oil or gas fields. These costs will vary greatly depending on the depth of the depleted production zone, the status of the drill holes, the availability of distribution pipelines, etc. If a field is still producing, the operating costs of injecting CO_2 are small, about 10 cents per 1,000 cubic feet. In an abandoned field, the costs are much greater. The casing of every well has to be checked and repaired, the integrity of dry holes determined, compressors installed and distribution pipeline laid down. The total cost of injection of 1,000 cubic feet of CO_2 in the case of an abandoned field would be $1.00 to $2.00 per 1,000 cubic feet.

The potential for disposal of carbon dioxide in old petroleum fields is limited by the availability of depleted fields. Cumulative natural gas production up to the present is about 600 trillion cubic feet. If all these fields could be used for CO_2 disposal, then about 9 billion tons of carbon could be sequestered as carbon dioxide in these fields. At the present rate of total CO_2 production, 1.2 billion tons of carbon per year, the fields would be filled in eight years. If only the CO_2 generated during electricity production were to be stored underground, all existing depleted gas fields would be filled in 25 years.

The total cost for disposing of CO_2 generated in the production of electricity by coal would be about 6 to 8 cents per kilowatt hour, an amount that would effectively double the cost of electricity. In addition, the above estimates do not take into account the CO_2 generated by the energy used to remove the CO_2 from the flue gas, transport it and dispose of it. Finally, there is a definite limit to available disposal space. Dumping in the deep ocean is a possibility because ocean mixing time is about 1,000 years, but the transportation and pumping costs are much greater than those for underground disposal.

Question 3:

What energy technologies do you feel should be receiving more or less attention and funding from the Department of Energy and the legislators on Capitol Hill? What role do you see conservation playing in future energy policy?

Answer:

Conservation is essential and must play a primary role in future energy policy. As fuel costs increase, conservation makes good economic sense. In terms of CO_2 production, conservation, or increased efficiency, is in many cases the most cost-effective way of reducing CO_2 emissions at present. For coal-powered electrical utilities, improving the thermal efficiency from 32% to 40% decreases CO_2 emissions by one-fourth. Technologies to achieve such efficiencies are available but are currently marginally economic. One feature of the carbon tax I have proposed is the shifting of economics in such a way that more efficient methods of burning coal are encouraged. A carbon emission tax would also place a premium on high mileage automobiles, thus encouraging conservation in the transportation sector, the single greatest source of CO_2 under public control. The biggest gains in conservation are to be made in transportation and in electrical generation. Requiring conservation in consumer appliances may have the value of raising conservation consciousness but, in fact, makes a minor contribution to decreasing CO_2 emissions.

As indicated in my testimony, I believe we need to reemphasize research into fission reactors. Research should be aimed at enhancing safety and reliability, increasing efficiency to mitigate waste heat disposal problems and enlarging the number of options with regard to reactor size. There is no current justification for pursuing breeder reactor technology at any level other than the underlying scientific and technical base. The fusion program should be supported as a laboratory activity. Basic scientific problems remain unresolved. Further, fusion will pose safety and radioactive waste handling problems that differ from those of fission reactors but are potentially as serious. A major concern for the development of fusion is that if these problems are not adequately addressed at the outset, the public perception linking fusion with the H-bomb will hamper future development, if the time comes when development is warranted.

In the fossil energy field, I would urge that the clean coal technology program be pushed in the direction of higher efficiency burning. Technologies to scrub SO_2 are well in hand and NO_X removal has advanced rapidly. Clearly, coal will continue to be a significant fuel and the more efficiently it is burned, the lower the carbon dioxide and carbon monoxide emissions. Research into the recovery of natural gas from geopressurized fluids and from methane hydrates is justified as these resources are many years away from becoming commercial.

EPRI
Electric Power
Research Institute

December 4, 1987

DEC 07 1987

Hon. J. Bennett Johnston
Chairman
U.S. Senate Committee on
Energy and Natural Resources
Washington, DC 20510-6150

Dear Mr. Johnston:

This letter is in reply to your correspondence of November 18 requesting clarification of elements of my testimony on climate change. My supplementary remarks are in two parts: the first answering your questions, and the second addressing interests of the Committee on energy efficiencies and the nuclear power alternative.

Answers to Your Questions.

1. Your prepared testimony discussed nitrous oxide and its role as a greenhouse gas. Doesn't nitrogen oxide also play a role because it helps to form tropospheric ozone (another greenhouse gas)?

The nitrogen oxides, nitric oxide (NO) and nitrogen dioxide (NO_2) do indeed play a role in production of tropospheric ozone. Nitrous oxide (N_2O) is not chemically reactive in the troposphere. The gases (NO and NO_2) are linked with hydrocarbon vapors to generate photochemical smog, a major component of which is ozone. Tropospheric ozone reduction is governed under the Clean Air Act as a "criteria" pollutant. At this stage, the ozone in the troposophere generally is not considered an important factor as a greenhouse gas in global climate change.

2. Would a reduction in nitrogen oxide emissions ameliorate the twin problems of the greenhouse effect and acid deposition?

Measures to reduce emissions of NO_x (NO and NO_2) may or may not result in the reduction of N_2O emissions. The relationship between N_2O and NO_x is the subject of current research. Currently, reduction of NO_x emissions would reduce

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acid deposition because of a decrease in nitric acid (HNO_3) formed in the troposphere. Since N_2O is not chemically reactive in the troposphere, its reduction there would not influence acidic deposition.

3. Low NO_x burners can reduce nitrogen oxide emissions. What would be the percentage increase in the cost of power from a typical generating plant retrofitted with a low-NO_x burner? (Please answer for gas, oil and coal plants).

New fossil fuel power generation sources have used low-NO_x burners to meet national new source performance standards (NSPS) NO_x (NO and NO_2) emission limits since 1971. These burners may be amenable to being retrofitted on existing power plant boilers that predate the NSPS for NO_x. Because of great variations in boiler geometries and operating conditions, however, such retrofits may be more complicated than construction of new units with equivalent output. In addition, the stricter operating requirements of low-NO_x burners may impose the need for upgrades to aging or outdated fuel and air supply systems. EPRI and the utility industry are currently evaluating the performance, reliability, and cost of low-NO_x burners and other combustion modifications for the major pre-NSPS coal-fired boiler types as well as oil- and gas-fired boilers via a series of full-scale demonstration projects. This work has not focused on N_2O emissions or their control. These demonstrations, which will be completed by 1991, will also help quantify the portion of the existing boiler population which is amenable to these retrofits. For low-NO_x burners, retrofit costs are highly site-specific and may depend on the desired level of NO_x control. Current capital cost estimates for a low-NO_x burner retrofit range from \$5-25/kW. Because of inherent limitations in pilot testing, O&M cost estimates await completion of ongoing demonstration activities. However, no significant O&M costs are anticipated. The cost of electricity for pre-NSPS fossil-fuel-fired plants ranges from 30-50 mills/kW-hr, depending on the age of the unit, years of remaining life, capacity factor, fuel costs, existing pollution control requirements, and location. Using only capital costs and typical EPRI economic premises, the impact of low-NO_x burner retrofits, once proven, on the cost of electricity is anticipated to be less than 3%. These costs are substantially lower than those expected for NO_x flue gas treatment processes.

4. On pp. 6-7 of your prepared statement, you seem to stress that the greenhouse effect is hypothetical, and that we have only a very limited understanding of the global climate. Do you disagree with the other witnesses at these hearings who have testified that a global warming is very likely, or nearly a certainty? What are the areas of dispute between you and these scientists?

The mean surface air temperature has tended to increase since 1880, with a notable period of decrease between 1940 and 1970. The various reports of increase in sea level from thermal expansion of water are also consistent with warming. The theory of atmospheric radiation links atmospheric carbon dioxide increases with the general trend of air temperature changes. Nevertheless, one must explain the period of cooling roughly from 1940 to 1970 when CO_2 emissions were increasing significantly. As implied from Dr. Hansen's testimony, this apparent paradox involves climate forcing processes that are roughly the same magnitude as changes in the greenhouse gases. Dr. Hansen noted as forcing processes the thermal capacity of the oceans and stratospheric aerosols. Also of concern are the radiative interactions with tropospheric aerosols, (water) clouds, and biospheric interactions that he did not mention. The role of the biosphere is not well understood at present and models are ill-equipped to handle these interactions. Furthermore, there have been few if any sensitivity studies of cloud cover and tropospheric aerosol changes worldwide over long periods of time that would qualify current interpretation of temperature data, and the present climate models.

We now know that global temperature changes over the last 100,000 years have been substantial, and fluctuations in natural CO_2 levels appear to be associated with these changes. Whether this is a cause or effect linkage is not known at present.

I agree that a general warming trend has taken place in the past, and that increasing atmospheric CO_2 is one of many factors contributing to this change. However, I feel the uncertainties surrounding the climate forcing agents noted above and the unexplained cooling from 1940 to 1966 suggest that we are not at all certain that the warming trend will continue.

5. In your direct testimony before the Committee, you commented on data presented in Dr. Hansen's testimony on temperature changes in this century. Did you state that during the period 1940 to about 1980, there was a significant increase in atmospheric CO_2 accompanied by a temperature decrease? In your mind, is this evidence of the uncertainty of current climate models?

I noted the period of cooling with increasing atmospheric CO_2, roughly from 1940 to 1980. More precisely, examining Figure 12 in Dr. Hansen's testimony, that comment should be confined to the period 1938-1967 (29 years). Since 1967, the surface air temperature has tended to increase again. The net change in temperature from 1880 to 1987 amounts to approximately 0.7°C, with the cooling between 1938 and 1967 of 0.2°C (about 30% of 0.7°C). It is not clear from the data record if the change of 0.7°C over the past 100 years is a result of rising CO_2 emissions or is a peak-to-trough change in a long-term climatic oscillation from natural disturbances. Comparison between the model calculations and the temperature does not necessarily support the reliability of predictions. The models are necessarily limited constructs of reality, and must be verified in several ways with a variety of data. It is important to state and appreciate the theoretical and computational limitations of the climate models in this context. In any case, Dr. Hansen, in his testimony, has noted that the progressive warming will have to persist into the 1990's to a temperature change of about 1°C before we can be statistically confident of the linkage with changes in atmospheric greenhouse gases. I agree with his assessment of uncertainty. This uncertainty is in the predictive models, but more important, it is also in our interpretation of a natural phenomenon.

6. Our examination of Fig. 12 of Dr. Hansen's testimony indicates that there was a net increase in global temperature during the period 1940-1980, with the "delta T" rising from about 0.2 to 0.3. Temperature rose and fell several times over this period. Do you interpret Fig. 12 the same way?

No, as stated above, I interpret the data in Figure 12 to show a net decline beginning in 1938 and lasting roughly through 1967, with annual fluctuations rising and falling in this period. Since 1967 the net temperature pattern has trended upward again, rising in some years and falling in others. This pattern of change is not repeated as strongly in the 100-year record, but a similar extended cooling period occurred between 1899 and 1910. The 10-30 year peak-trough changes signal one of many "oscillations" in temperature that need to be accounted for or explained, if possible, in addressing long-term climate drifts or trends. Scientific understanding of these details of climatic history are essential to establishing the reliability of predictions into the future.

My main point in noting the period between 1940 and 1980 is to show that interpretations of climate warming with atmospheric CO_2 increase depend in part on the length of record of temperature change (or other climate indicators). Through the 1970's, scientists were puzzled by the decrease in temperature with increase in CO_2 levels between 1938 and 1967. Only with a much longer record can we identify whether the warming trend is truly persistent or is simply part of a naturally occurring, long-term climate fluctuation.

7. In your opinion, does the rise and fall in temperature (1940-1980) illustrate the uncertainty of current climate models? Or do climate modelers expect such year-to-year fluctuations? Do you agree with Dr. Hansen that temperature trends in the last 100 years represent important empirical evidence that supports the theory of the greenhouse effect and indicates that a global warming is underway?

The decrease in temperature beginning around 1933 extending for over 30 years illustrates uncertainty in scientific interpretation, not modeling. The rise and fall in temperatures observed between 1937 and 1970, indeed observations of temperature extending back over 100 years, record both natural and possible man-made factors affecting climate. Indirect temperature records, deduced from glacial ice and deep sea sediments, show that temperatures have fluctuated for thousands of years, long before human activity might have influenced the climate. The record of recent decades, including the 29-year cooling beginning around 1938, reflects the net result of all the known and unknown natural and man-made factors. The difficulty in interpreting any occurrence of a measurable greenhouse effect from CO_2 and other gases is separating that effect from the many natural factors that are as important, or more so, in determining climate.

Dr. Hansen's testimony indicates that he interprets the 100-year trend as support for the greenhouse effect. However, careful reading of his argument also indicates that within the uncertainty of climate variation, the warming trend is not statistically significant at the 99% confidence level. He states that we must accrue trend data into the 90's to be confident of the reliability of the inferred warming and CO_2 concentration (or other greenhouse gas) linkages. I agree with this analysis, and his discussion of uncertainty.

In spite of the need for additional data to verify a predicted temperature warming of about 1°C, the available data and theory provide circumstantial evidence for the warming trend predicted by the theory. The theoretical studies need to incorporate more knowledge of the biosphere and other interactions, while discussions of socio-economic consequences of warming are broadened. Certainly it is not premature to expand the second area of effort to provide an early knowledge and perspective of the potential socio-economic effects of hypothesized climate change.

Energy Efficiency and Nuclear Power

The electric utility industry has been concerned about energy conservation and end-use efficiency for some time. In response to the industry interest in assisting customers to use electricity more effectively, EPRI has a major program component addressing these subjects.

New and improved end-use technologies are being studied. For instance, residential heating, ventilation, and air conditioning; commercial air conditioning and lighting; and industrial motor drives together account for approximately 60% of the nation's electricity consumption. Products now being developed by EPRI -- e.g., more efficient heat pumps, lighting equipment, and adjustable speed drives -- directly address these opportunities.

Efficiency gains can also be achieved by substituting electric energy for direct oil and gas usage in certain applications where electricity can be used more efficiently than these other energy forms. The translation of thermal energy into an end use is sometimes more efficient through intermediate conversion to electric energy than directly. Electric vehicles and heat pumps are examples of such opportunities. The use of electrochemical separation of material replacing distillation in the food processing industry is another example. Here, a unit of electric energy can replace several units of inefficient direct heating. This would decrease CO_2 emissions per unit of thermal energy used.

By the year 2000, the energy conservation potential achievable with application of efficient technologies now being developed could save over 5 quadrillion BTUs (quads) of electric energy, and shift two quads from premium fuels (gasoline or natural gas) to the use of electricity. U.S. consumption is expected to be roughly 85 quads per annum in 2000. Thus energy efficiency by the cited technologies would represent a roughly

7% decrease in energy consumption. The contribution of EPRI's technology to this potential could be as much as one quad, resulting from its role in accelerating the development and expediting the utility industry's application of these technologies.

Nuclear power can contribute to reduced air pollutant emissions from electric generation, as attested to by Hans Blix, Director General of the International Atomic Energy Agency:*

> "In several countries the nuclear programmes have clearly helped significantly to avoid emissions of pollutants which could have resulted from alternative fuels. The nuclear programme in France helped to reduce sulphur dioxide emissions from power plants by 50% since 1980. In Finland, a 40% reduction has been achieved, and in Belgium 66%."

Nuclear power also would reduce CO_2 emissions in a corresponding way. Nuclear power has been viewed unfavorably in the last decade because of rising costs and conern as to potential health hazards arriving from accidents. With the concern for the consequences of climate change and increasing greenhouse gas concentrations, nuclear power offers an important alternative for new plant capacity. The rising costs in part are a design, construction and operational consequence of experience, and in part a regulatory proliferation. The latter is a problem to be addressed by both the government and the industry. The former can be greatly improved with (a) recent improvements in retrofit technology to improve safety, extend power plant lifetime and improve efficiency (e.g., reduction in down time), and (b) standardization of new designs and enhanced operational efficiency with new technology. New designs are currently being reviewed for generic certification so that a "uniform" plant technology will be approved where needed, and only the siting issues will be subject to case-by-case review. EPRI's programs are critically involved in technology development for existing and new plants.

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* Opening Statement for the Conference on Nuclear Power Performance and Safety, Vienna, Austria, September 28, 1987

With regard to risk assessment, there are studies that place perspective on the relative risks involved in different fuel use technologies. Quoting from one study:**

> "None of the three systems (coal, oil or nuclear)+ is free of hazard, whether in normal operation, or in potential for major incident. For coal-burning systems, the largest incident could cause hundreds of deaths. For the other two systems each taken as a whole, there is a small risk of involving up to tens of thousands of deaths. Because of the limitations of the assessments, it is better to express the overall conclusion in qualitative terms: 'The expert reports reviewed here suggest that within the obvious limits of these estimates, suitably sited, constructed, and maintained nuclear systems of the types reviewed, involve no more, and probably less, risk, than oil- or coal-burning systems, taking account in each case of the whole fuel cycle.'"

Accepting this, it would appear that nuclear technology may have received an excessively negative treatment relative to fossil fuel technology. With appropriate public participation

** Cohen, A.V. and D.K. Pritchard, 1980; "Comparative Risks of Electricity Production Systems: A Critical Survey of the Literature"; Research Paper 11, Health & Safety Executive, Her Majesty's Stationery Office, London.

+ Insert by author

in decision making, nuclear power appears to be a viable alternative for consideration of future U.S. electric energy needs.

Thank you for the opportunity to add thoughts to my initial submittal.

Yours sincerely,

G. M. Hidy

George M. Hidy
Vice President and Director
Environment Division

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